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FLUID CONTAMINATION OF AIRCRAFT-CABIN AIR AND BREATHING OXYGEN

K. L. Paciorek, Ph. D.
J. H. Nakahara, B.A.
R. H. Kratzer, Ph. D.
Ultrasystems, Incorporated
2400 Michelson Drive
Irvine, California 92715

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USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

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NOTICES

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This technical report has been reviewed and is approved for publication.

LEONARD J. LUSKUS, Ph.D.
Project Scientist

RICHARD L. MILLER, Ph.D.
Supervisor

LAWRENCE J. ENDERS
Colonel, USAF, MC
Commander

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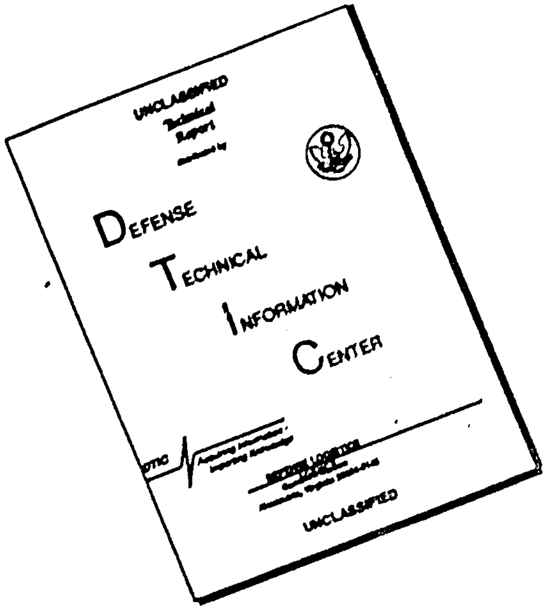

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From different manufacturers, a series of lubricating oils (MIL-L-7808), hydraulic fluids (MIL-H-5606), and heat-transfer fluids (MIL-C-47220) were obtained to test their potential for contaminating aircraft breathing air and oxygen. No significant differences were detectable in the compositions of lubricating oils and hydraulic fluids, irrespective of the origin, including fluids recovered after service in an aircraft. The two heat-transfer fluids of interest were single compounds.

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20. ABSTRACT (Continued)

Under normal operating conditions, the hydraulic and heat-transfer fluids afforded minimal quantities of products. The lubricating oils volatized to a large degree; the mists consisted essentially of unchanged starting materials.

Tests simulating line rupture with fluid spilling onto a hot, 450°C (850°F), metal surface in the presence of air resulted in excessive fluid degradation. In all instances, significant quantities of hydrocarbons, carbonyls, and alcohols were produced. Among these, the highly toxic formaldehyde, acrolein, formic acid, and formates were found and quantitated.

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FLUID CONTAMINATION OF AIRCRAFT-CABIN AIR AND BREATHING OXYGEN

INTRODUCTION

The Air Force is developing self-contained oxygen-concentrating systems for generating breathing oxygen on aircraft. All systems proposed to date intend to utilize aircraft-engine bleed air as the oxygen source. This air, under normal operating conditions, comes into contact with lubricating oils. The engine bleed air may come in contact also with hydraulic and coolant fluids (normally completely contained) if they spill, for example, onto the hot engine manifold as a result of a line or seal leak or rupture. Because of the high temperatures involved, these fluids may vaporize and/or decompose into more volatile, partially oxidized products that can become entrained in the engine bleed air and thus be transported to the oxygen-concentrating unit--potentially ending up as a contaminant of the breathing oxygen produced.

Depending on their nature and to a degree their quantity, these entrained "foreign" components of the engine bleed air may impair the functioning of the oxygen concentration unit. If these entrained species are carried beyond this unit into the breathing-oxygen supply, the crew using this oxygen may be physiologically affected. The objective of this program was to determine to what extent these aircraft fluids become entrained and/or are degraded under various normal and emergency operating conditions, and to identify and quantitate all products formed.

All military aircraft fluids are regulated by performance specifications, whereas their composition--e.g., the type of base fluid and the nature of the additive package--is not specified and thus may vary from manufacturer to manufacturer. Accordingly, another objective of this program was to determine variations in composition between manufacturers for each fluid category and to establish the extent to which fluids of various origins, including used or aged fluids, differ in regard to oxidative thermal stability and to formation of specific volatile degradation products.

TESTING, RESULTS, AND DISCUSSION

Three types of fluids with the potential for contaminating aircraft-cabin air are the lubricating oils, hydraulic fluids, and heat-transfer liquids. Each of these materials has to satisfy certain criteria as delineated by Government specifications; however, these criteria pertain only to physical properties and not to chemical composition.

A number of manufacturers or suppliers for each of the three fluid categories have qualified their products as conforming with Government specifications. It is logical to assume that the "recipes" utilized (i.e., the specific combinations of base ingredients and additives) to achieve these performance standards are not identical and that therefore the components of these fluids, all of which meet the same military specifications, may be different. Thus, the objective of this program was not only to determine the thermal oxidative behavior of a fluid representative of a given class, but also to find out differences, if any, within a given fluid class, depending on manufacturer. Also, to permit more meaningful predictions insofar as products formation is concerned, we needed to assess the effect of aging in actual service. The testing regime represented the actual working conditions of the specific fluid categories and also the potential conditions expected during system failure, e.g., line rupture.

The testing and results of this program are discussed in the following subsections: Fluid Procurement and Characterization, Dynamic Testing of Lubricating Oils, Fluid Testing Under Quiescent Conditions, and Line-Rupture Simulating Tests.

Fluid Procurement and Characterization

All manufacturers given in the Qualified Products List (supplied with the Request for Proposal of this contract) for lubricating oil (MIL-L-7808), hydraulic fluid (MIL-H-5606), and coolant fluid (MIL-C-47220) were contacted. Nine of the materials listed there were no longer available (Table 1) due either to discontinued production or inability to meet new specifications. The fluids we obtained are listed in Table 2.

The three unused lubricating oils exhibited very similar, although not identical, infrared spectra. We selected the spectrum of Turbo Oil ETO 2389 as typical (Fig. 1). The most pronounced difference in chemical composition was between Brayco Conojet 880X and the two other oils; this was substantiated by the gas chromatography (GC) data summarized in Table 3. Due to poor peak separation, the relative component concentrations in these compilations are not given in the usual form of area/μl; instead, the attenuation approximates this function. The used lubricating oil, MLO 78-295, exhibited an infrared spectrum (Fig. 2) and gas chromatogram essentially identical with those obtained from Turbo Oil ETO 2389 and PQ Turbine Oil 8365.

To further characterize the fluids and assess the materials' volatility, differential thermal (DTA) and thermogravimetric (TGA) scans were obtained; representative curves are depicted in Figures 3 and 4.

According to Air Force Material Laboratory (AFML) personnel[1], the latest MIL-Spec on lubricating oils is L-7808G. These fluids are apparently composed of trimethylolpropane and/or pentaerythritol esters. The difference between the D specification (Brayco Conojet 880X) and the G specification is obvious from the GC data given in Table 3. None of the constituents were identified since the mass spectrometer detector was not employed because of the high temperatures used and the resultant column bleed into the source. Although not included in this report, chromatograms were obtained by programming from 50° to 300°C at 8°C/min to determine the presence, if any, of volatile constituents and to provide a basis for subsequent comparisons with air-entrained species and the residual oils. Using the programmed GC, the first peak was observed at 24.5 min (column temperature, 246°C).

One used and nine unused hydraulic fluids were procured (Table 2). The two Chevron fluids were supplied by Standard Oil of California but originated from Bray Oil Co., and since three other hydraulic fluids were obtained directly from Bray Oil Co., the two from Standard Oil of California were not analyzed.

All hydraulic fluids, including the used fluid (MLO 78-294), exhibited identical infrared spectra; each material showed the presence of a carbonyl group (see Figs. 5 and 6). The gas chromatographic analyses indicated (from the peak appearance, relative intensity, and retention times) that Univis J-13 and Petrofluid 4606 were virtually identical. All members of the Brayco series and the Royco 756D exhibited superimposable gas chromatograms, but these differed from those given by Univis J-13 and Petrofluid 4606 (compare Tables 4 and 5). Based on the differential thermal data, the hydraulic fluids are relatively low boiling, ~260-300°C (see Fig. 7). This high volatility is further confirmed by the thermogravimetric analysis, where at ~300°C all the material was evaporated (see Fig. 8).

According to AFML personnel[1], the MIL-Spec H-5606 C and D fluids show little difference and both are currently used. The main constituents of these fluids are supposed to be naphthenic hydrocarbons admixed with 17-20% of methyl methacrylate viscosity improver (MW ~160,000), 1% of methylene-di-t-butylphenol antioxidant, 1/2-1% of tricresyl phosphate, and DC-200 silicone oil (in ppm quantities) antifoaming agent. In agreement with this information, hydrocarbons appear to be the major constituents, based on GC data and supported by infrared spectral analysis. The poly(methyl methacrylate)

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[1] C. E. Snyder, AFML/MBT, Wright Patterson AFB, Ohio. Personal communication and letter dtd 22 Nov 78, "Request for Used Engine Oil and Hydraulic Fluid Samples and Technical Information--Contract AF 33615-78-C-0612."

was most likely retained by the column. Inasmuch as 2,6-di-t-butyl-4-methylphenol was tentatively identified, we can assume that this antioxidant is used together with methylene-di-t-butylphenol.

Three cooling fluids--Coolanol 45, Coolanol 35, and Coolanol 25R--were received from Monsanto Corp. Based on gas chromatographic analysis, Coolanol 45 consists essentially of a single component, $>$ 98% of sample, with five impurities adding up to less than 2%. The same, but with impurities amounting to less than 1%, applies to Coolanol 25R. Coolanol 35 is apparently a mixture of 4 major and 2 minor components present in 16, 35, 32, 13, 2, and 2%, respectively. From the gas chromatographic analyses, we can deduce that in this series, Coolanol 25R is the lowest and Coolanol 45 the highest boiling fluid; differential thermal analyses (see Figs. 9-11) support this stipulation to a degree, although the difference between Coolanol 45 and Coolanol 35 is not as pronounced as would be expected. The TGA curves (see Figs. 12-14) are in agreement with the GC retention times measured.

The three materials exhibited closely related infrared spectra; this was particularly true of Coolanol 45 and Coolanol 35. The infrared spectra of Coolanol 25R and Coolanol 45 are given in Figures 15 and 16, respectively. The mass spectral breakdown pattern of Coolanol 25R (Table 6) indicates the arrangement $[CH_3CH_2CH(CH_2CH_3)CH_2O]_4Si$; i.e.,

m/e, 433 = M + 1

m/e, 403 = M - 29 $[C_2H_5]$

m/e, 361 = M - 71 $[CH(CH_2CH_3)CH_2CH_3]$

m/e, 347 = M - 85 $[CH_2CH(CH_2CH_3)CH_2CH_3]$

The fragmentation pattern for Coolanol 45 (Table 7) indicates the arrangement $[CH_3CH_2CH_2CH_2CH(CH_2CH_3)CH_2O]_4Si$; i.e.,

m/e, 545 = M + 1

m/e, 515 = M - 29 $[C_2H_5]$

m/e, 487 = M - 57 $[C_4H_9]$

m/e, 445 = M - 99 $[CH(CH_2CH_3)C_4H_9]$

m/e, 431 = M - 113 $[CH_2CH(CH_2CH_3)C_4H_9]$

Dynamic Testing of Lubricating Oils

In service, lubricating oils are constantly agitated by the moving parts of the engine at elevated temperatures in the presence of flowing air. The service temperature for MIL-Spec 7808G lubricating oil is approximately 175°C (350°F) according to information received from AFML personnel[1]. To simulate this environment, a test assembly (Fig. 17) was designed and constructed. Figure 18 shows the detailed schematics of the reactor portion of this apparatus.

In a typical experiment, first the oil to be tested, ~10 g, was introduced into the reactor. With stopcocks C and D closed, the system was then evacuated via stopcock G. Subsequently, dry air (passed over an Ascarite-filled column connected to the high vacuum manifold) was introduced via the same stopcock and the apparatus was brought up to atmospheric pressure. Traps 2 and 3 were then cooled with liquid nitrogen, and trap 1 with a -78°C bath; more air was added until the pressure held steady at ~650 mm. At that point, stopcock G was closed and stopcocks C and D were opened, the heated line section was brought to the selected temperature, the Manostat pump was put into operation at 28 liters/hr (1 SCFH), and the metal bath (preheated to the selected temperature) was put under the reactor. Heating at the selected temperature was continued for the specified period of time. After the reaction conclusion (heating and air circulation discontinued and oil brought to room temperature), a sample of the noncondensibles was withdrawn via stopcock E; the remainder of the noncondensibles were pumped out via stopcock G and discarded. Following this, traps 1-3 were warmed to ambient temperature; the room-temperature volatiles were pumped via stopcock G into a trapping system, then fractionated and analyzed. The involatile residue in traps 1, 2, and 3 and the condensates entrapped in glass wool and collected in the round-bottom flask were weighed and subjected to gas chromatography, mass spectral analysis, infrared spectral analysis, and in certain instances to molecular weight determination. Table 8 summarizes the tests carried out, and Table 9 lists the volatiles produced.

Data presented in Table 7 indicate that even at 300°C the extent of degradation is negligible, as measured by products formed (excluding water) and the characteristics of the mists and residual fluid. The infrared spectra and mass spectra (see Tables 10-15) of the mists, residual oils, and untreated oils were almost identical. The gas chromatograms of residual fluids showed some depletion of the earlier peaks, whereas in the mists these were enriched. This was particularly evident in the mist of the test performed at 300°C, wherein an unidentified component was eluted (in relatively high quantity) at 23 min. Under the same GC conditions, the untreated oil exhibited significant peaks only beyond 30 min. The presence of the lower fractions or possibly breakdown products in the mists is further confirmed by the somewhat lowered molecular weights (compare Table 8). The high quantity of water "produced" in all the tests must originate from the silicone tubing of the Manostat assembly--as proven by the test where no oil was employed, yet water was collected.

Data in Table 9 show that hydrocarbons comprised the bulk of products. Carbonyls (namely ketones and aldehydes), although found only in small quantities, would be expected to be found in larger quantities on prolonged exposure. The quantity of the volatiles collected indicates that the used lubricating oil, MLO 78-295, formed more products than the other oils tested. The major compounds produced were apparently the C_8 and higher alcohols, as can be seen from Table 9. Additional (not determined) quantities of these alcohols were entrapped in the mist.

Fluid Testing Under Quiescent Conditions

These tests were tailored specifically for evaluating the thermal oxidative behavior, especially concerning volatiles production, of hydraulic and heat-transfer fluids. For comparison, Turbo Oil ETO 2389 was included in this series. The apparatus used (Fig. 19) was essentially the same setup as that used for the dynamic studies, the main difference being the elimination of the circulating pump, the loop-closing arrangement, and the stirring assembly. Using an all-glass system avoided the silicone-rubber "outgassing" mentioned previously and allowed the determination of oxygen depletion, if any. The total volume of the system was approximately 700 ml. The temperatures selected for specific fluid classes were based on the operating temperatures.

The quiescent tests are summarized in Table 16 which shows that the quantities of volatiles formed were minimal. In all instances, water was the main product. Without air flow, no mists were collected and oxygen uptake, if any, was too small to be detected by mass spectral and gas chromatographic analyses. The products found (see Tables 16 and 17) were in agreement with specific samples' compositions. Thus, in the case of hydraulic fluids Brayco Micronic 756E and MLO 78-294, methyl methacrylate was a major volatile product evolved--in agreement with the presence of poly(methyl methacrylate) in the fluids' formulation. The detection of 2-ethylbutanol and 2-ethylbutanal in the volatiles of Coolanol 25R, and 2-ethylhexanol in the volatiles of Coolanol 45, shows that at the temperatures employed, some hydrolysis of the silicate ester, as well as oxidation of the liberated alcohol, does take place.

Line-Rupture Simulating Tests

The engine manifolds in high-performance aircraft are believed to be at approximately 454°C (850°F). To simulate the condition under which a rupture of a line permits a fluid to contact the hot surface, the apparatus depicted in Figure 20 was designed and constructed. The diagram is self-explanatory. Note, however, that the heating element and the thermocouple are enclosed in separate quartz tubes which are sealed into the apparatus; thus, the fluid tested can never contact the heaters. With this method of heating, the stainless steel block can readily reach 500°C (932°F). Figure 21 shows the total system, including the line-rupture test apparatus, traps, and circulating pump.

The actual experimental procedure consisted of placing a weighed quantity of the test fluid into the reservoir. Subsequently, with stopcocks C and D closed, the system was evacuated via stopcock G. Following this, dry air, which was passed over an Ascarite-filled column, was introduced; traps 2 and 3 were cooled with liquid nitrogen and trap 1 with a -78°C bath. Then the pressure was brought up to ~ 580 mm. At that time, stopcock G was closed, stopcocks C and D were opened, and the circulating pump was put into operation; also, heating of the connecting line (180°C) and the metal block (450°C) within the line-rupture test apparatus was initiated. As soon as steady state (determined by thermocouple reading) was reached (~ 30 min), the dropping of fluid onto the hot surface was initiated. This was continued for a denoted period of time. The introduction of each drop was accompanied by immediate evaporation and mist formation. A certain degree of condensation took place within the line-rupture simulation apparatus, and the loss of material in this enclosure accounts for the low mass balances found.

Product separation was conducted in the same manner as in the dynamic thermal testing of lubricating oils. The only exception was that the materials volatile at room temperature were subsequently separated by fractional condensation, using traps held at -23, -78, and -196°C. Each condensate was then quantitatively analyzed by gas chromatography-mass spectroscopy and infrared spectroscopy.

The tests performed are summarized in Table 18, and the products liberated by the different fluids under these conditions are listed in Table 19.

In the case of the four lubricating oils, Turbo Oil ETO 2389, Brayco Conojet 880X, PQ Turbine Oil 8365, and MLO 78-295, the mists collected in the round-bottom flask, in the glass-wool-filled column, and in the cooled traps were found by gas chromatography and infrared spectral analysis to consist essentially of the starting materials. The only difference was that the earlier GC peaks were more pronounced in the mists. In the room-temperature volatile, liquid nitrogen condensible fraction, carbon dioxide and water were the two main products. Whether these originated wholly from the degradation of the oil or whether a portion of these two materials originated from the silicone tubing is unknown. Based on the blank runs performed in the past (see Table 8), no more than 37% of the water and carbon dioxide combined should be derived from the tubing. Table 19 shows that C_2-C_9

hydrocarbons and a variety of aldehydes and ketones accounted for the remainder of the products. The nature and quantity of products formed by the four lubricating oils were comparable (as seen from Table 19), although definite differences were present; e.g., the large quantity of 2-methyltetrahydrofuran detected among the volatiles of Brayco Conojet 880X.

The two hydraulic fluids, Brayco Micronic 756E and MLO 78-294, volatized mainly as a mist, which in both cases consisted almost exclusively of the starting materials admixed with small quantities of methyl methacrylate. The latter was also produced in the low-temperature static tests described earlier. In addition to methyl methacrylate, water, and carbon dioxide, the main products found were hydrocarbons, aldehydes, and ketones. The production of C_8-hydrocarbons was very pronounced in the case of MLO 78-294 fluid, which implies the presence of an additive containing these chains and corresponds to the finding of C_8-alcohol in the dynamic test at 200°C.

Mist formation was also the predominant action of the heat-transfer fluids. It was more evident in the case of Coolanol 25R than Coolanol 45, in agreement with the relative volatilities of the two materials. In both instances, the mists consisted largely of unchanged fluid. The nature and relative proportion of the compounds produced were in good agreement with the fluids' compositions. Thus, for Coolanol 25R, the major degradation process seems to be the hydrolysis of the silicate; i.e.,

$$[CH_3CH_2CH(CH_2CH_3)CH_2O]_4Si \xrightarrow{H_2O} CH_3CH_2CH(CH_2CH_3)CH_2OH \;+\; Si(OH)_4$$

The production of 2-ethylbutanal and the corresponding acid could occur via oxidation of the silicate ester itself or the oxidation of the alcohol, 2-ethylbutanol. The former seems more likely. The isolated shorter chain aldehydes and ketones are derived from the oxidative fragmentation of the hydrocarbon chain. The more complicated acetals and esters are most likely generated in the condensed phase (after condensation in the cold traps) from interaction of the primary products such as aldehydes, alcohols, and acids; e.g.,

$$\begin{array}{l} RCHO \;+\; 2\ CH_3CH_2CH(CH_2CH_3)CH_2OH \\ \quad\big\downarrow \\ RCH[OCH_2CH(CH_2CH_3)CH_2CH_3]_2 \end{array}$$

wherein R = CH_3 and/or CH_3CH_2. In an analogous fashion, the formation of 2-ethylhexanal and 2-ethylhexanol verifies the structure of Coolanol 45,

$[CH_3CH_2CH_2CH_2CH(CH_2CH_3)CH_2O]_4Si$; the origin of the shorter chain products can be readily ascertained, based on the major products found.

All three classes of fluids formed, at 450°C in air, substantial quantities of carbonyls (Table 19). Among these, the highly toxic acrolein (TLV, 0.25 mg/m^3) and formaldehyde (TLV, 3 mg/m^3) were found in quantities as high as 1.5 and 1.3 mg/g. The lubricating oils seemed to produce generally larger quantities of these products than the hydraulic and heat-transfer fluids, although the values varied almost as much within each fluid class as between the classes. The detection of formate esters shows clearly that the highly toxic formic acid (TLV, 9 mg/m^3) was also invariably formed under these conditions. Surprisingly, Coolanol 45 afforded the largest quantities of formaldehyde, formic acid, and formates. We believe that in the test, formic acid is originally formed, and the isolation of the esters is due to subsequent reaction of the acid with the various alcohols coproduced in the degradation process.

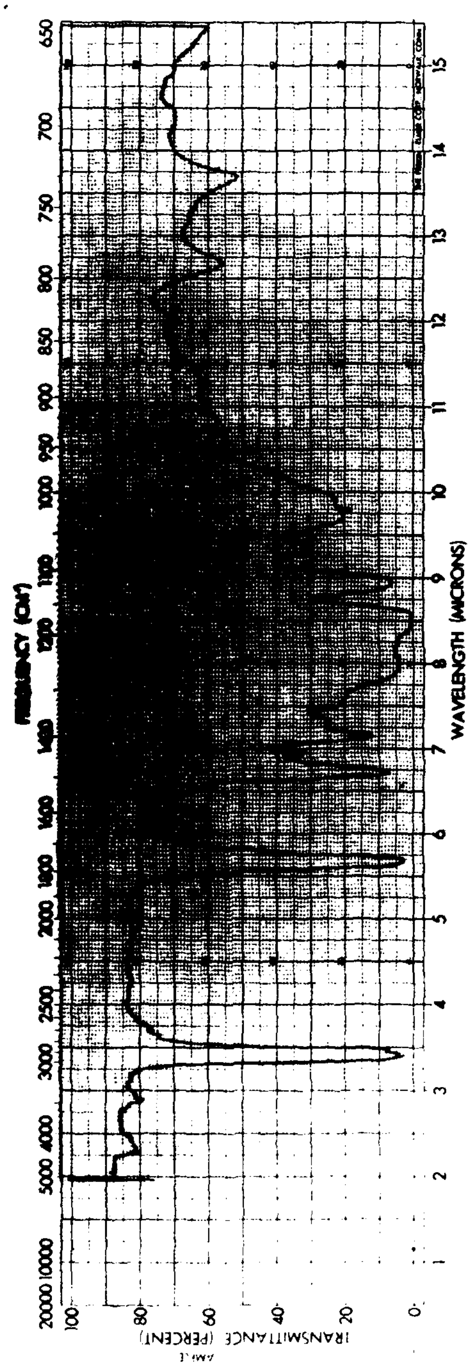

Figure 1. Infrared spectrum of MIL-L-7808 (Turbo Oil 2389).

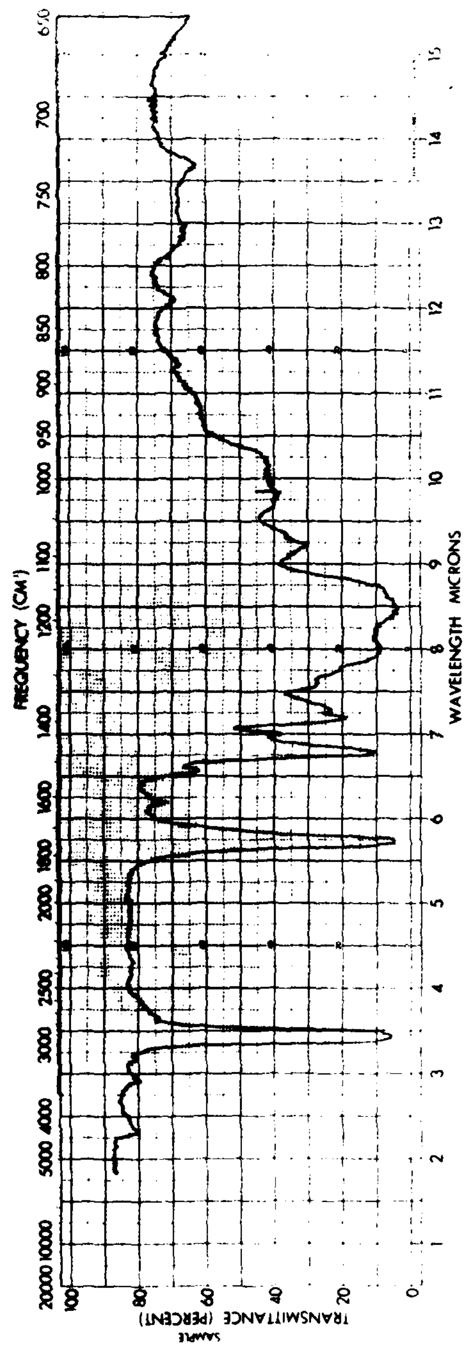

Figure 2. Infrared spectrum of MLO 78-295 (used MIL-L-7808).

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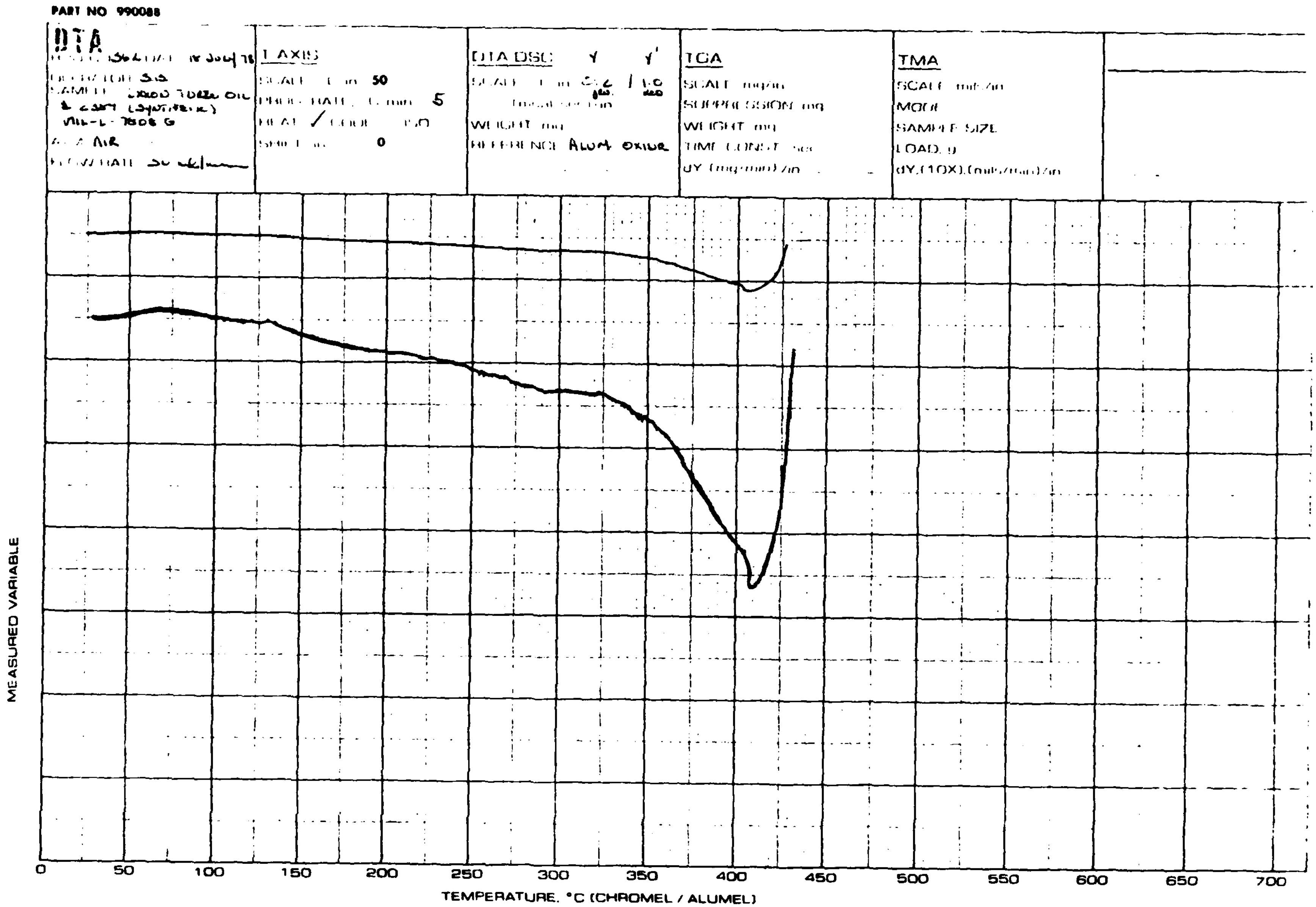

Figure 3. DTA of Turbo Oil 2389.

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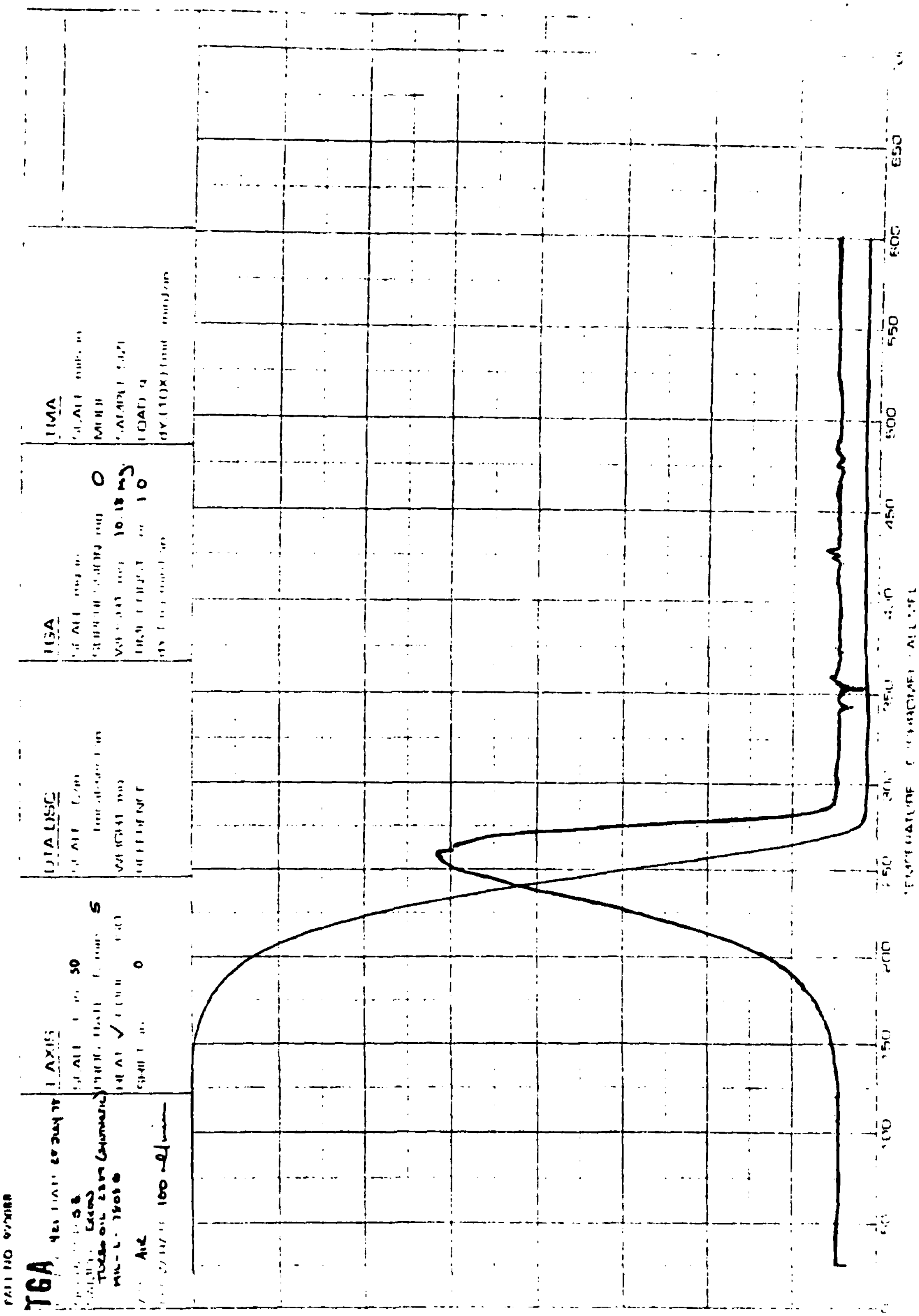

Figure 4. TGA of Turbo Oil 2389.

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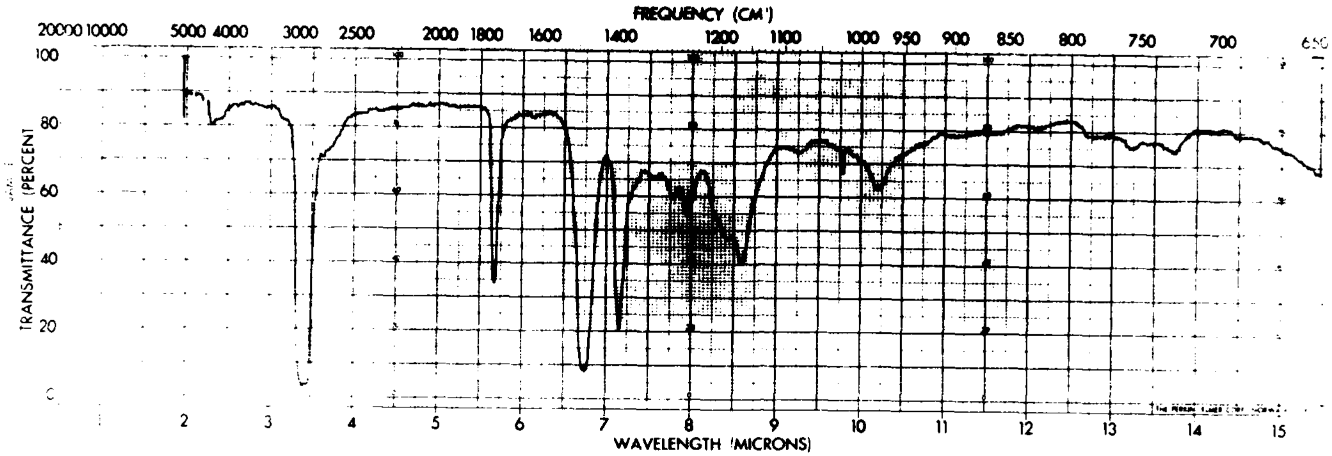

Figure 5. Infrared spectrum of MIL-H-5606 (Brayco Micronic 756E).

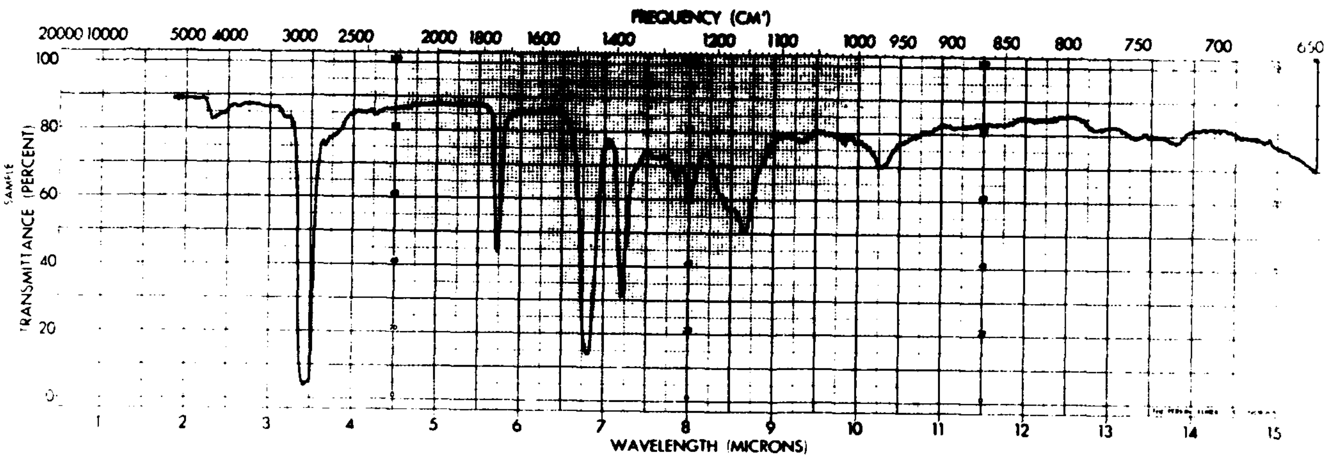

Figure 6. Infrared spectrum of MLO 78-294 (used MIL-H-5606).

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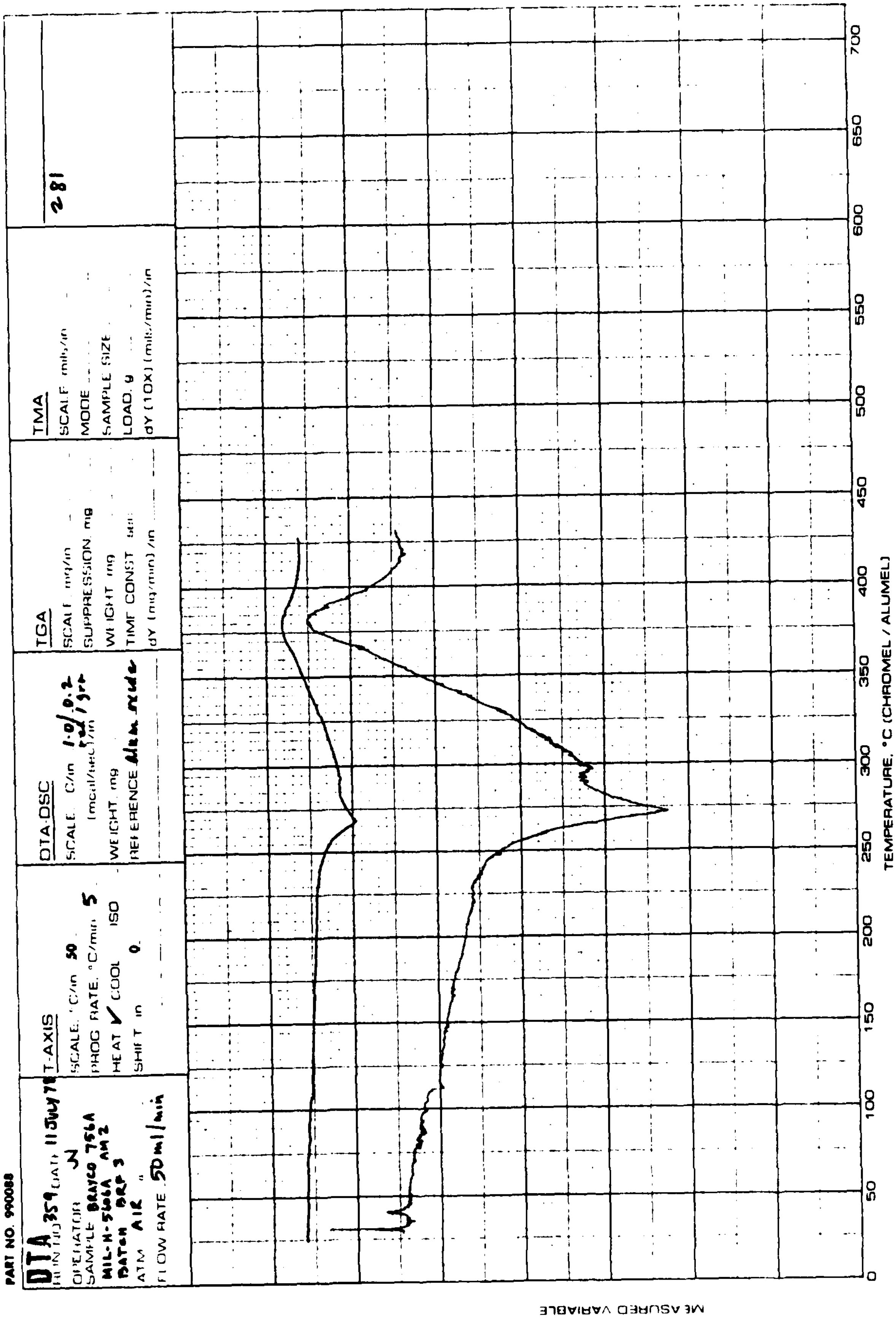

Figure 7. DTA of Brayco 756A.

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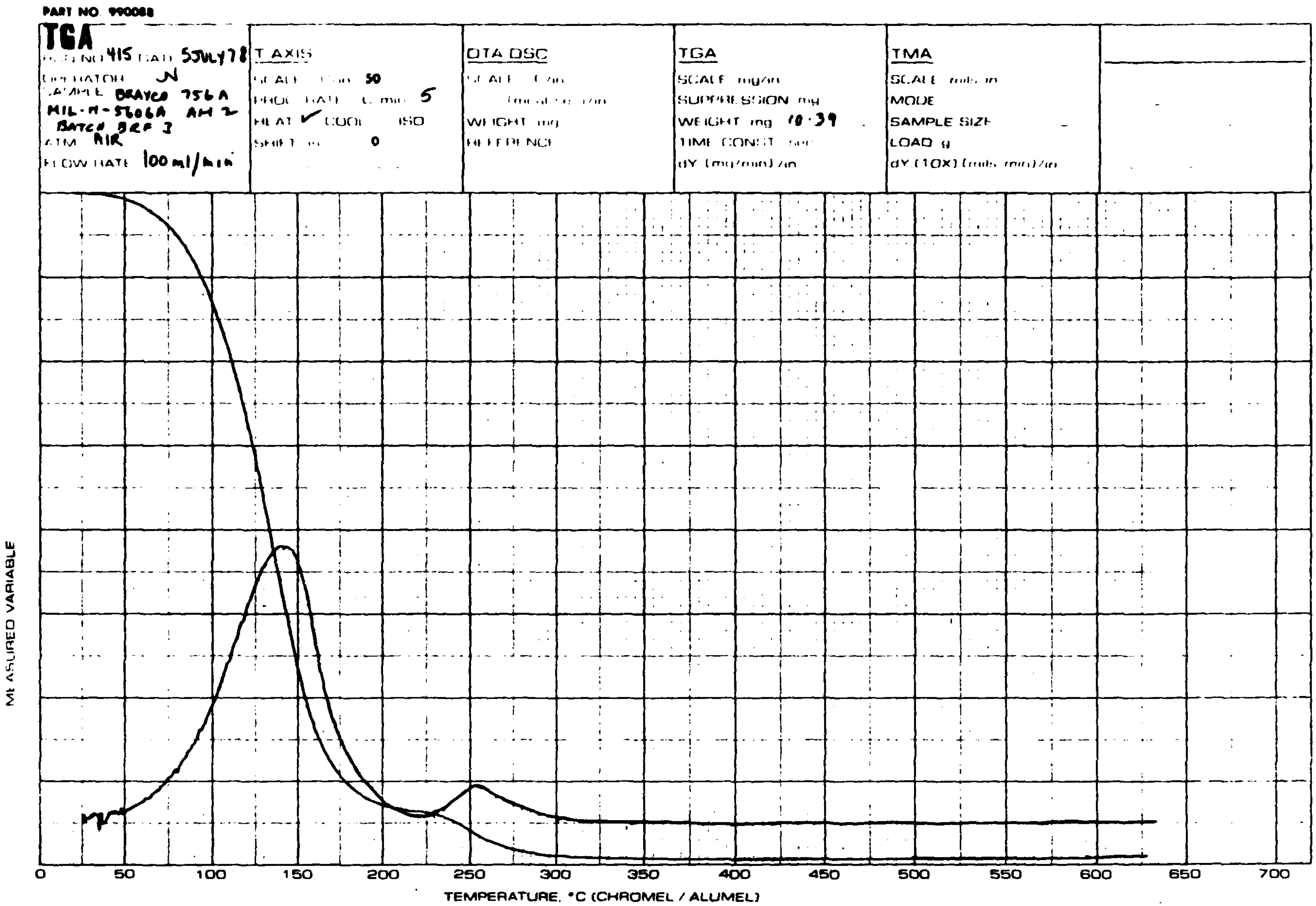

Figure 8. TGA of Brayco 756A.

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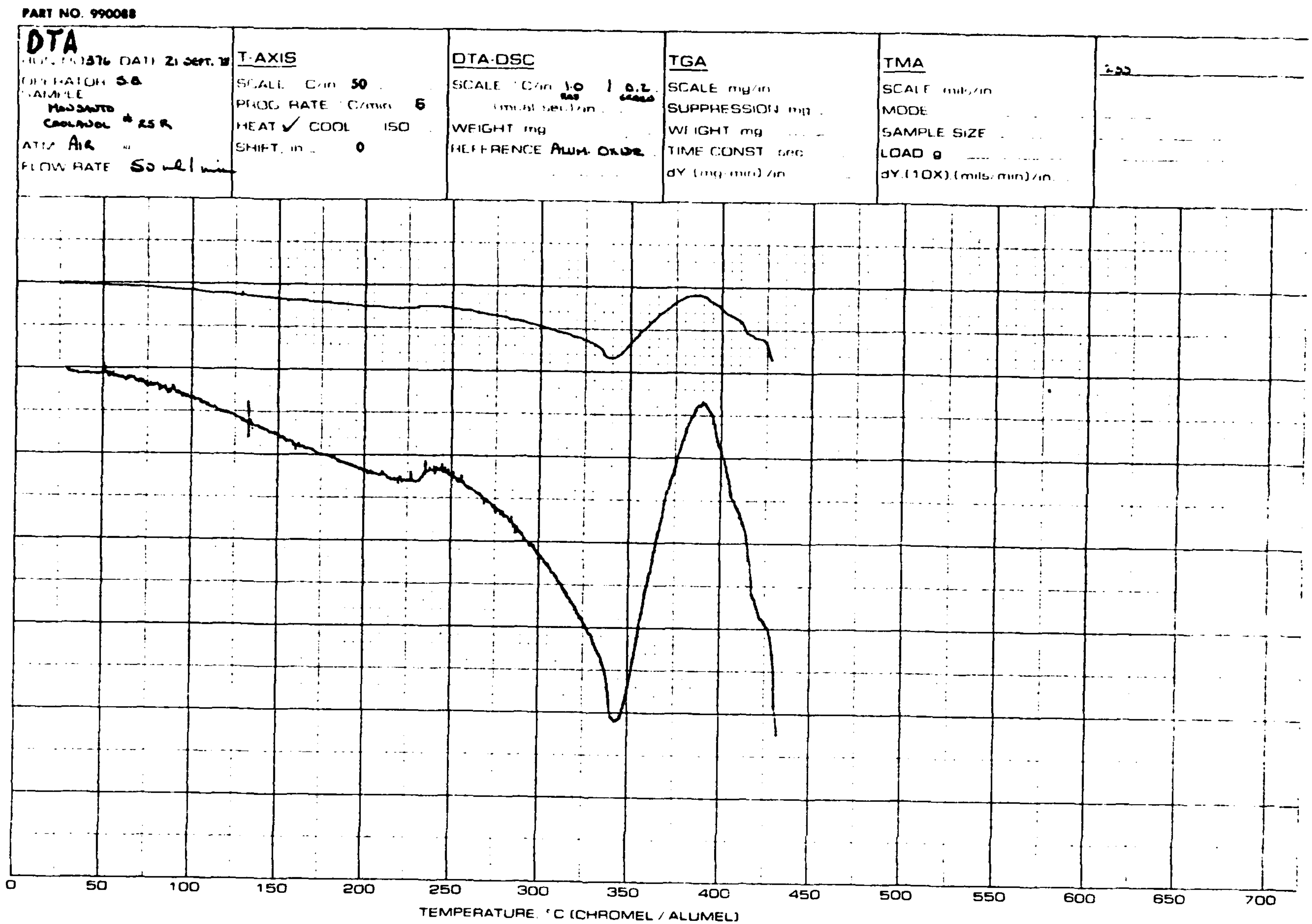

Figure 9. DTA of Coolanol 25R.

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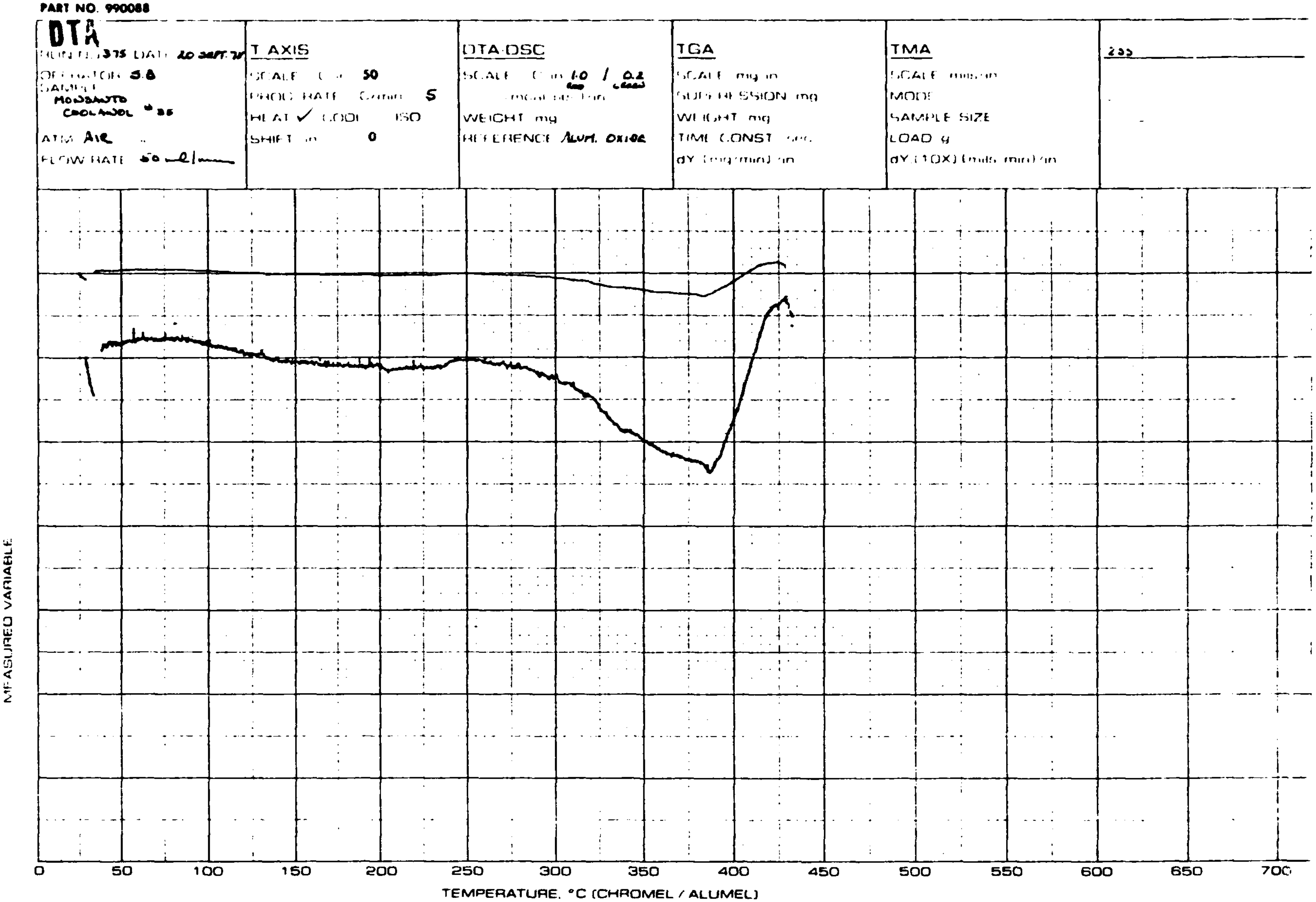

Figure 10. DTA of Coolanol 35.

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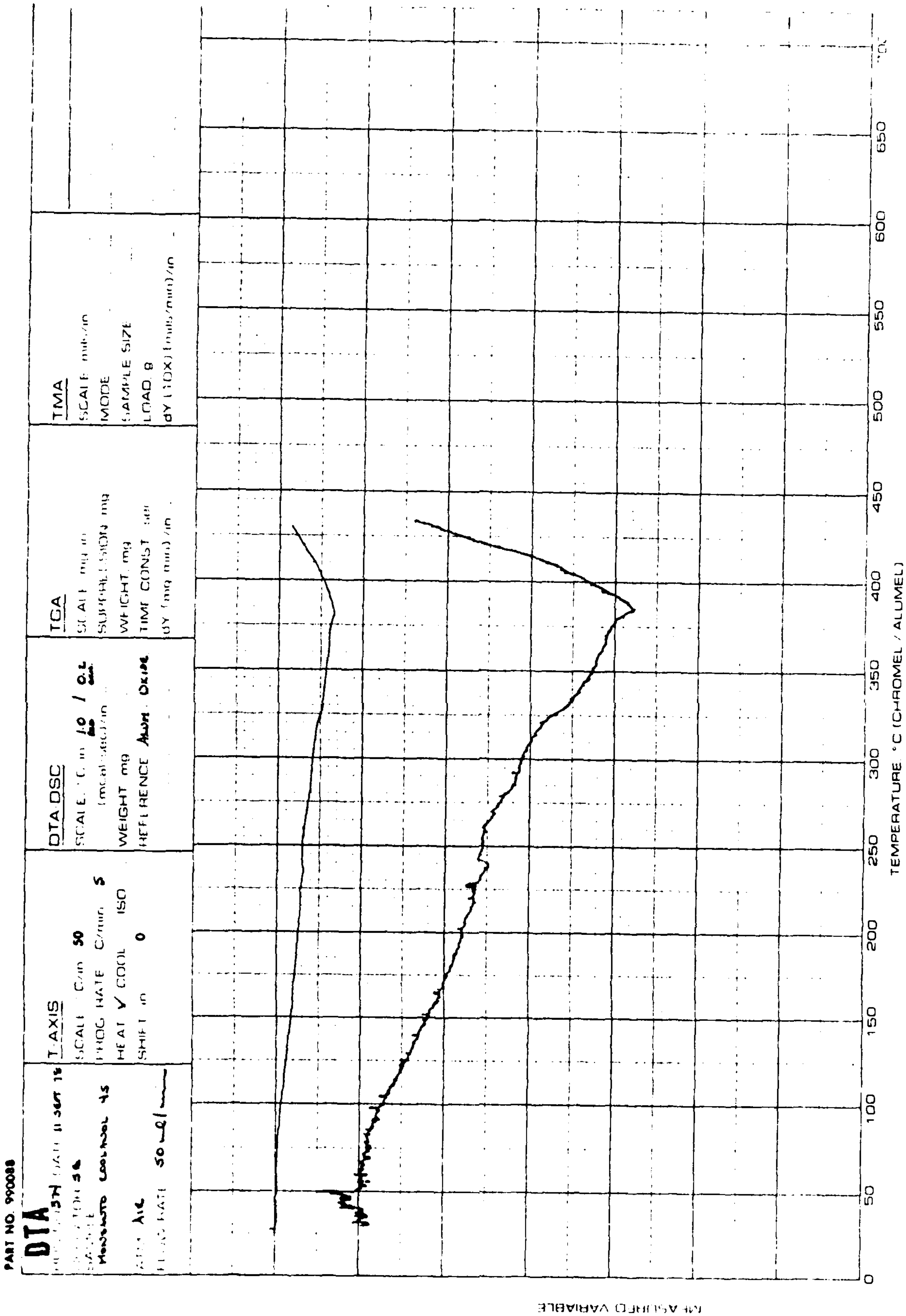

Figure 11. DTA of Coolanol 45.

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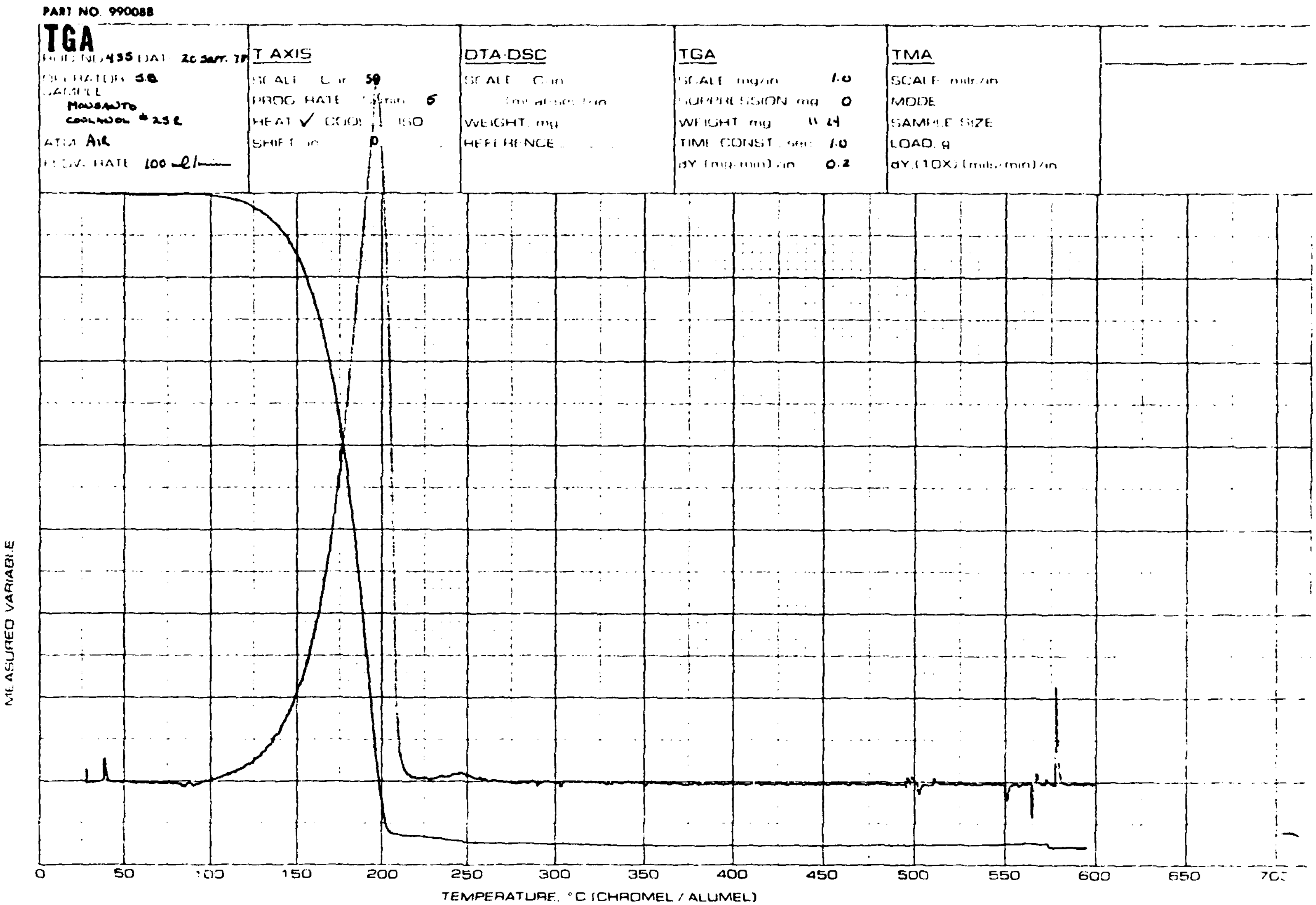

Figure 12. TGA of Coolanol 25R.

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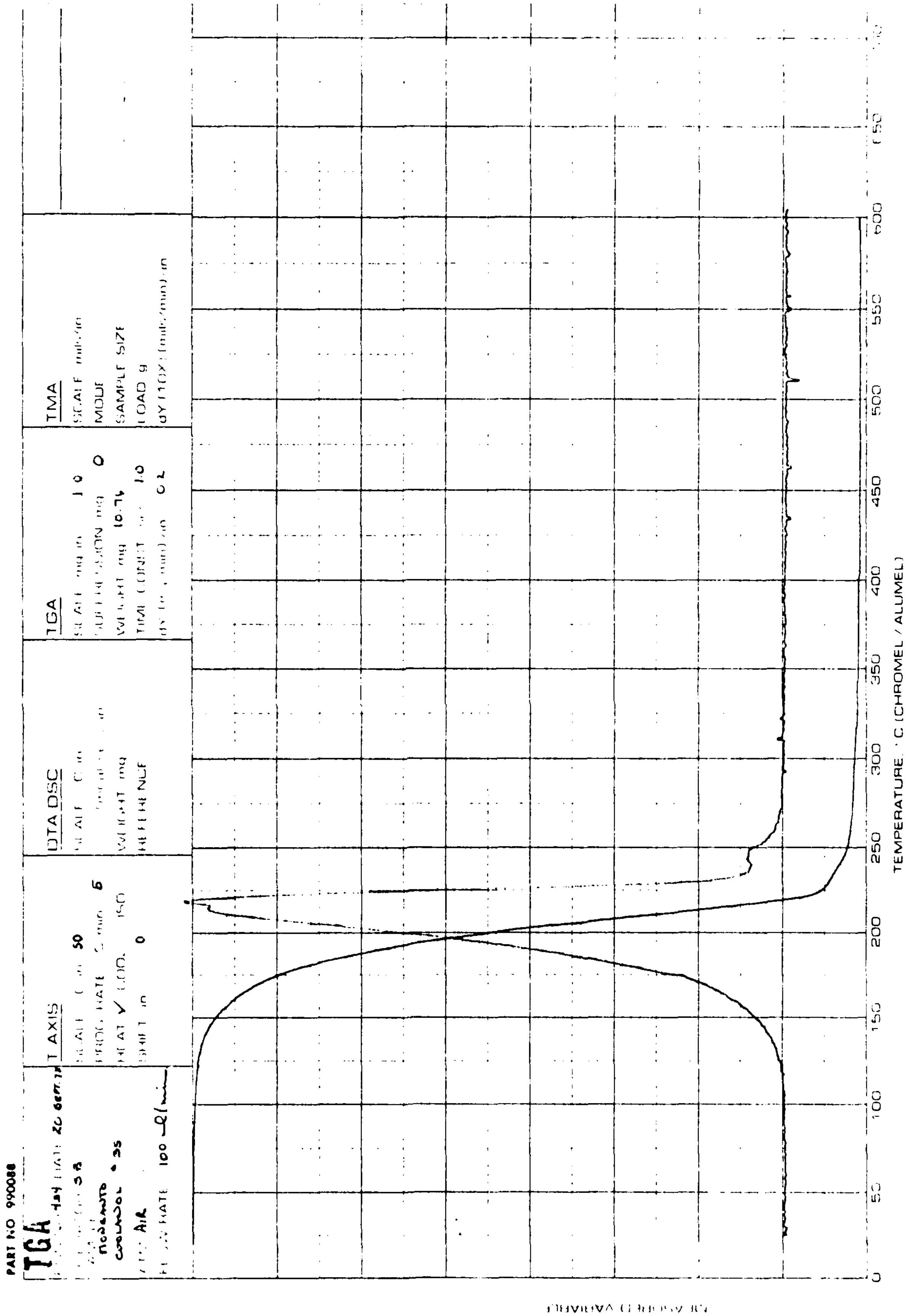

Figure 13. TGA of Coolanol 35.

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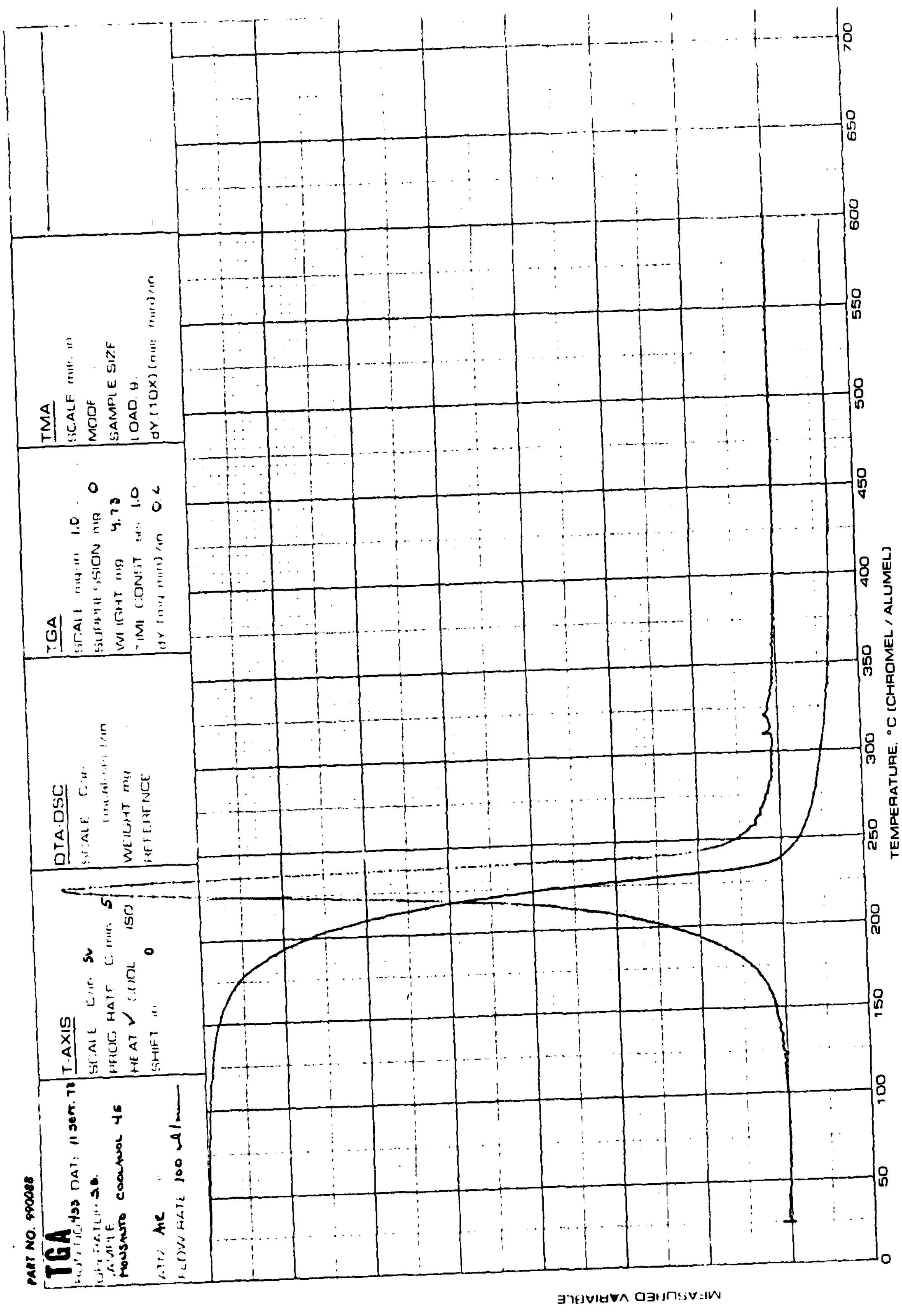

Figure 14. TGA of Coolanol 45.

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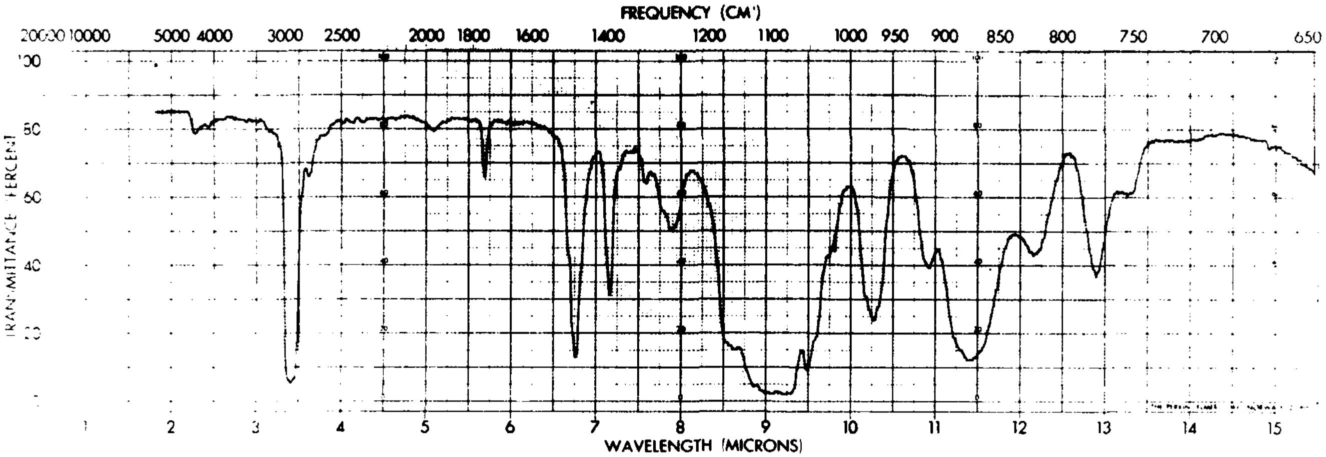

Figure 15. Infrared spectrum of MIL-C-47220 (Coolanol 25R).

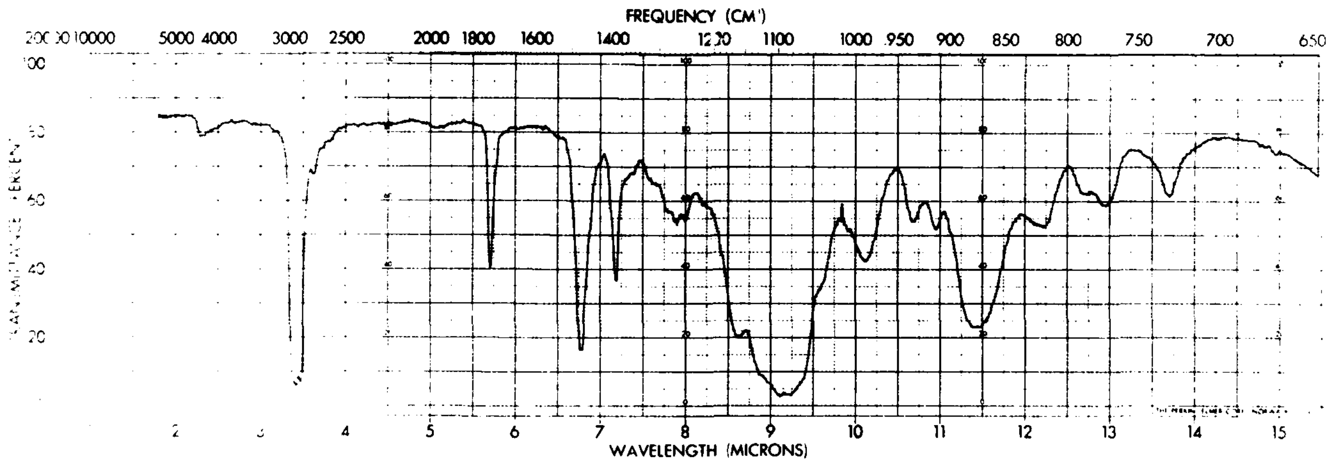

Figure 16. Infrared spectrum of MIL-C-47220 (Coolanol 45).

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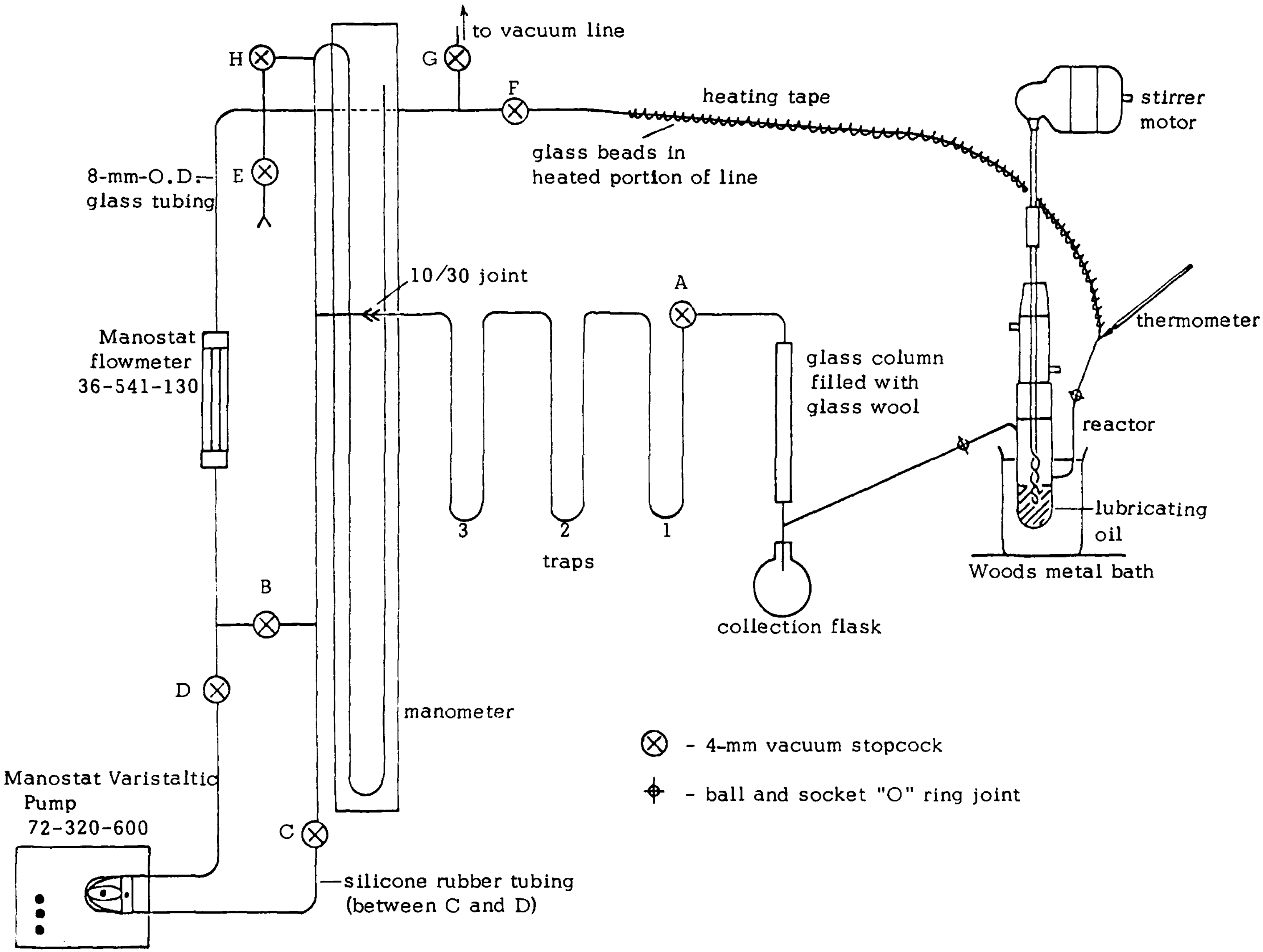

Figure 17. Lubricating-oil test assembly (modified).

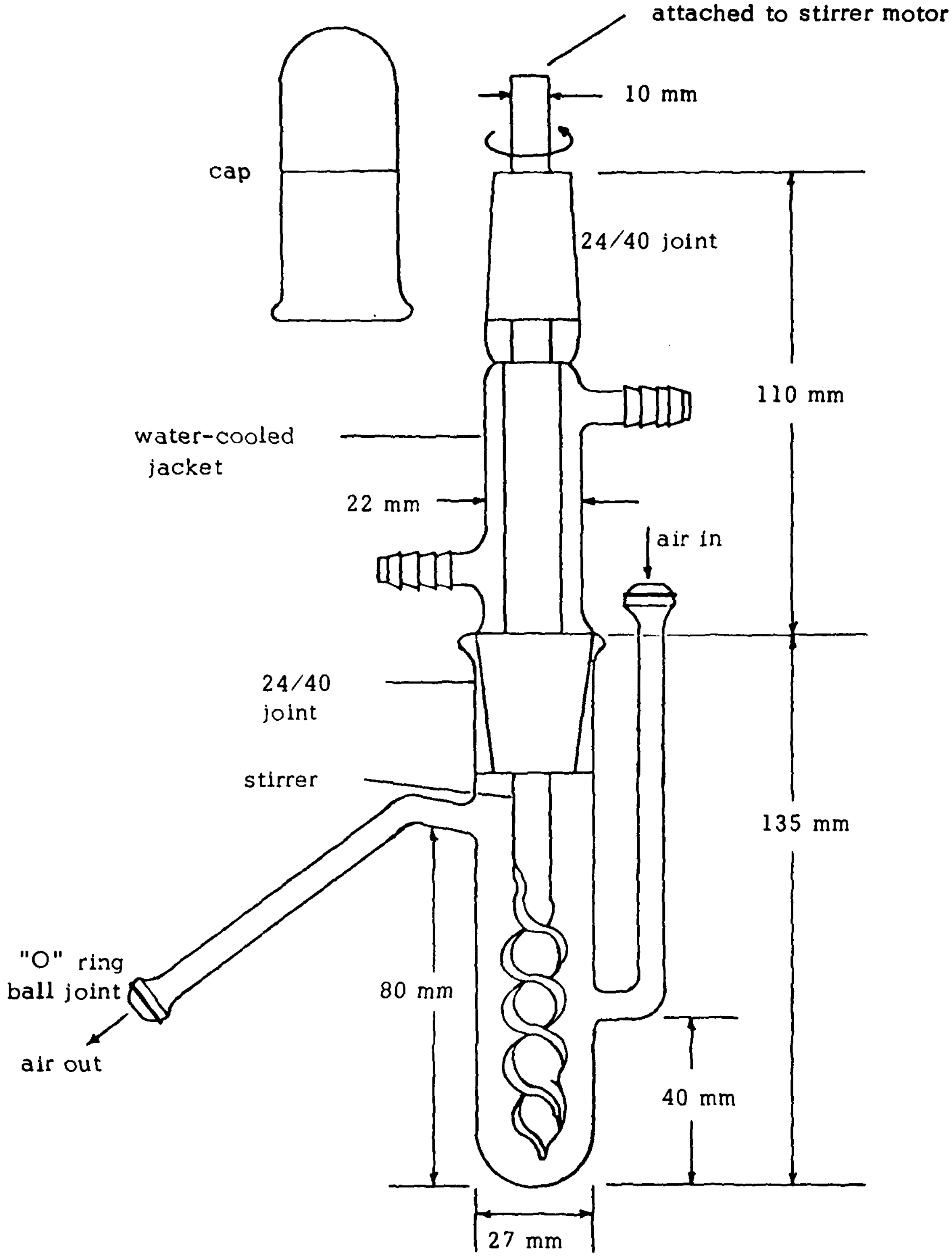

Figure 18. Test apparatus for lubricating oils.

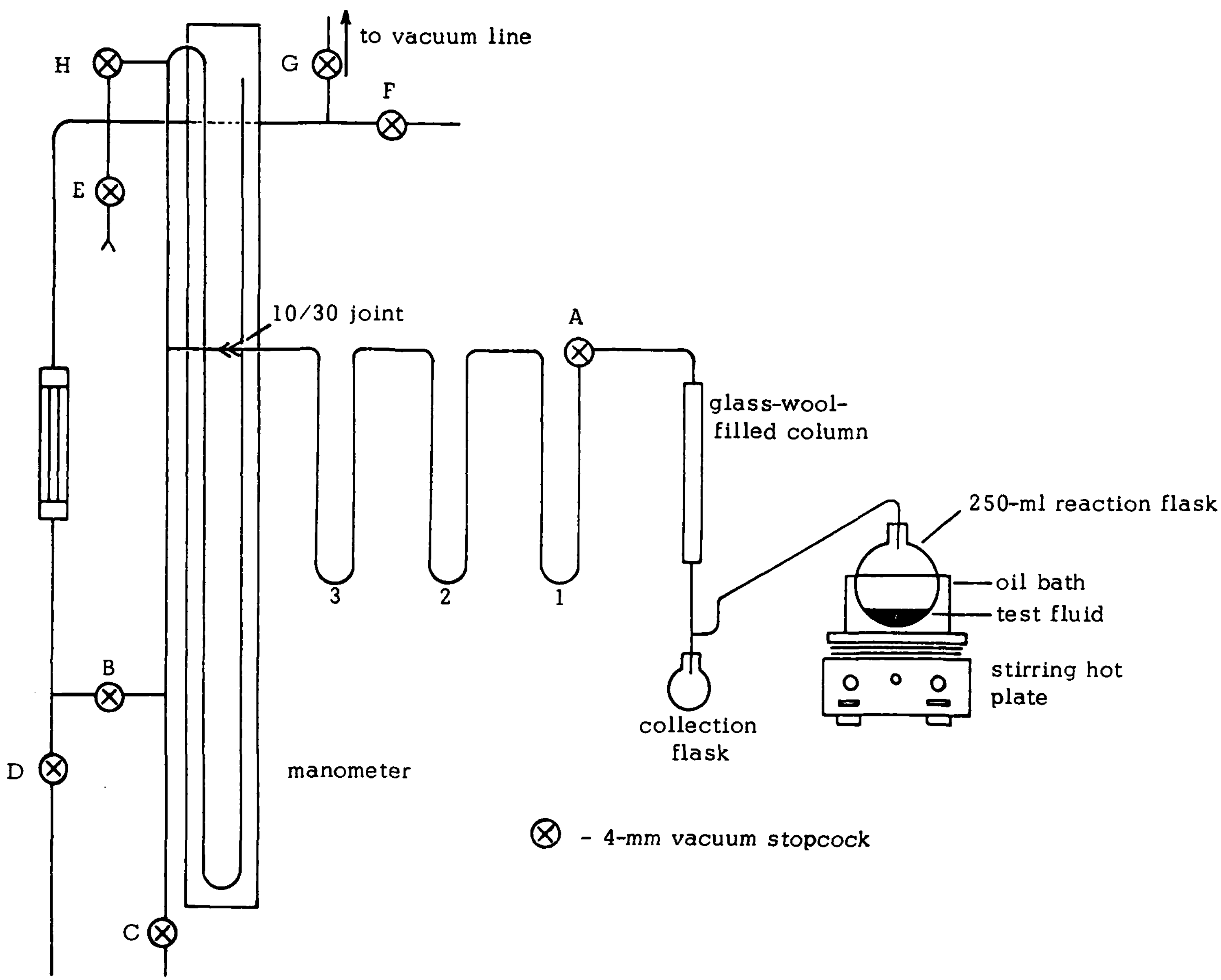

Figure 19. Quiescent testing assembly.

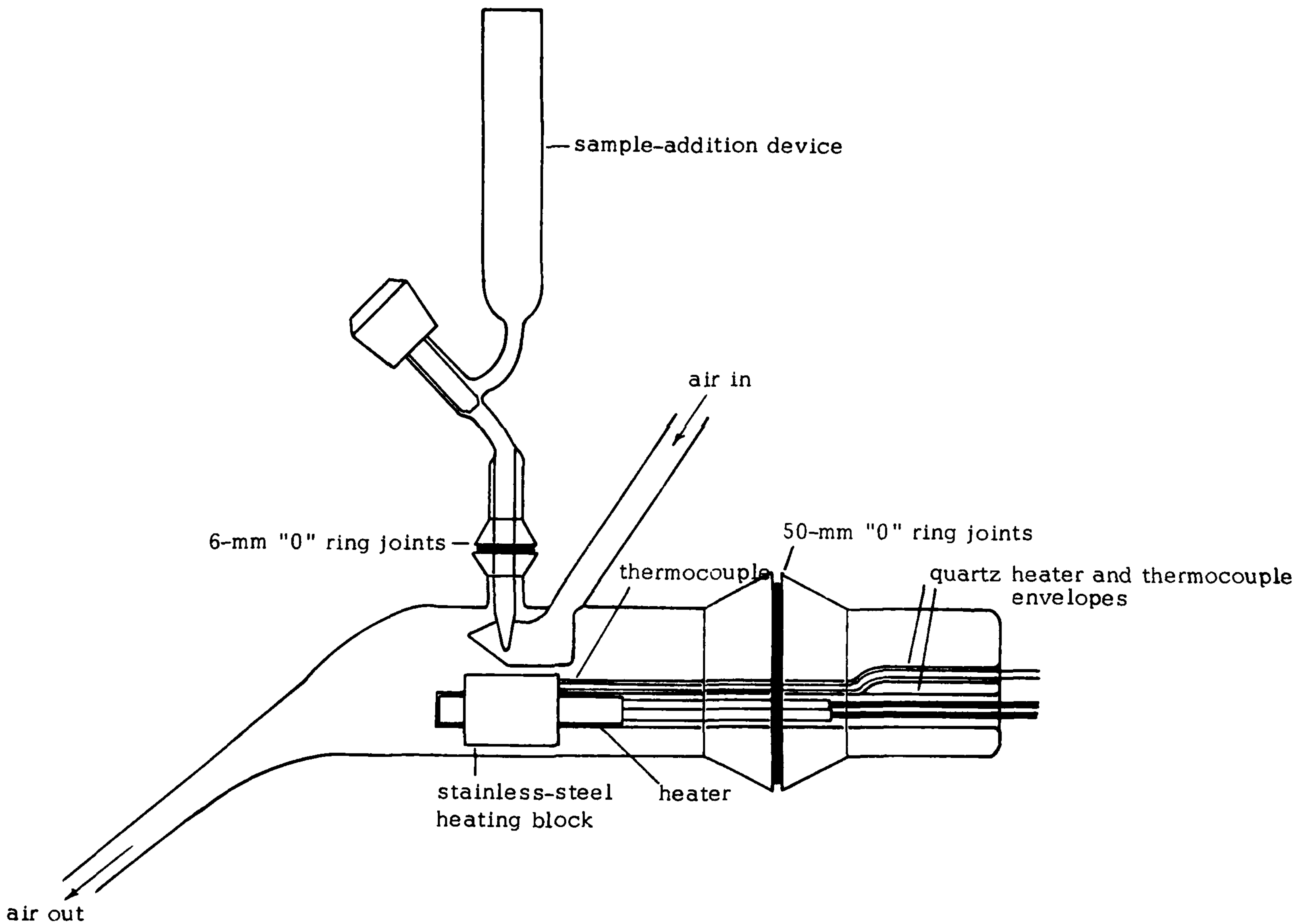

Figure 20. Line-rupture simulation test assembly.

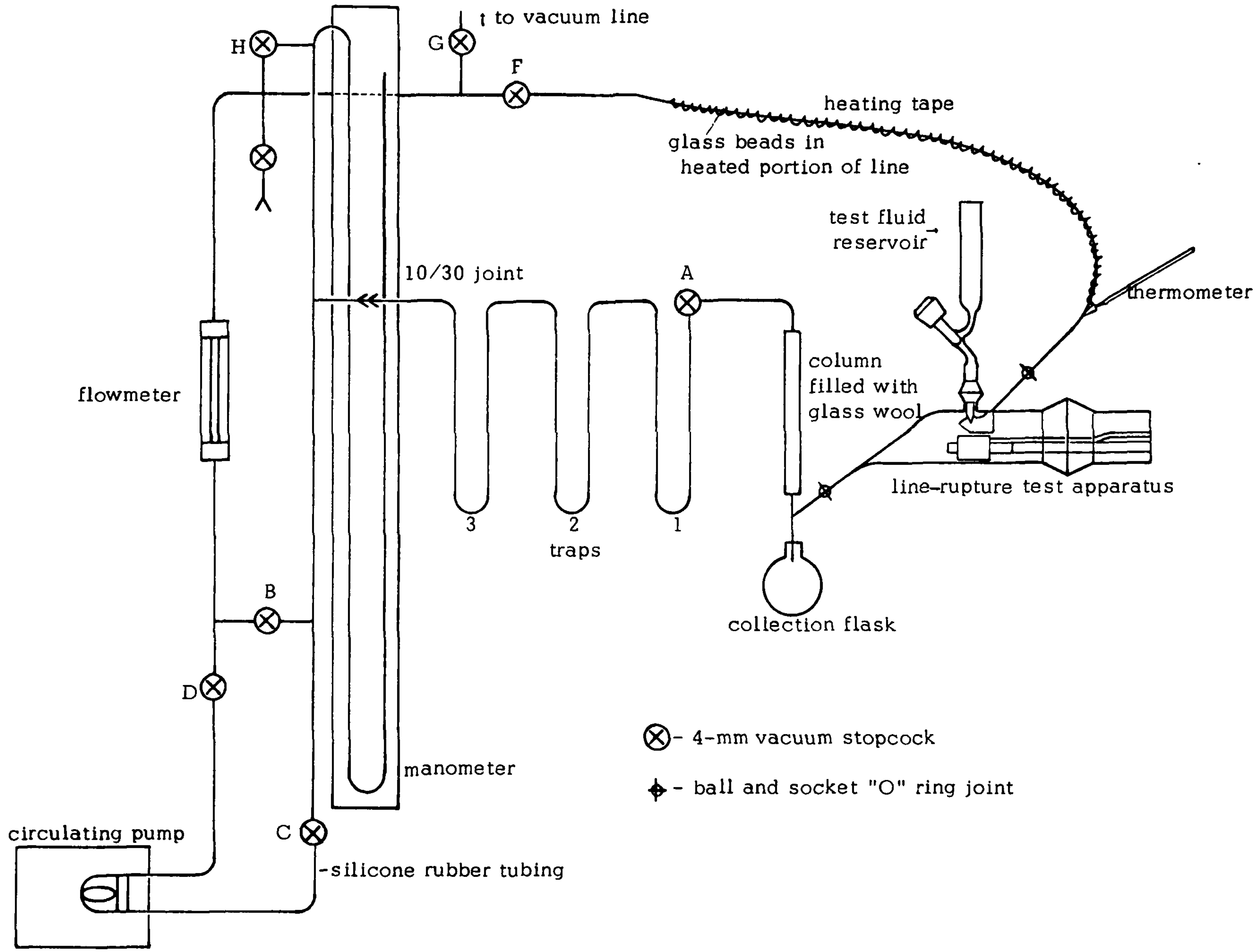

Figure 21. Total system for line-rupture simulation testing.

TABLE 1. LIST OF FLUIDS NO LONGER AVAILABLE

Specifications	Manufacturer identification	Manufacturer
MIL-L-7808	E-6825	Stauffer Chemical Co.
MIL-L-7808	PL-10568	Rohm and Haas Co.
MIL-L-7808	Royco 807HR, 808HR	Royal Lubricants Co.
MIL-H-5606	Hydroil 500	Stauffer Chemical Co.
MIL-H-5606	DS-437	Royal Lubricants Co.
MIL-H-5606	PED-3337 and PED-3565	Standard Oil of Calif.
MIL-C-47220	Flow Cool 180	Standard Oil of Calif.

TABLE 2. LIST OF FLUIDS RECEIVED

Specifications	Manufacturer identification	Manufacturer
MIL-L-7808G	Turbo Oil ETO 2389	Exxon Corp.
MIL-L-7808G	PQ Turbine Oil 8365[a]	American Oil Co.
MIL-L-7808D	Brayco Conojet 880X	Bray Oil Co.
MIL-L-7808[b]	MLO 78-295 (used fluid)	c
(Does not qualify	Univis J-13	Exxon Corp.)
MIL-H-5606C	Petrofluid 4606	Penreco
MIL-H-5606A	Brayco Micronic 756A	Bray Oil Co.
MIL-H-5606C	Brayco Micronic 756E	Bray Oil Co.
MIL-H-5606C	Brayco Micronic 757B	Bray Oil Co.
MIL-H-5606[b]	Royco 756D	Royal Lubricants Co.
MIL-H-5606D	PQ 4226[a]	American Oil Co.
MIL-H-5606A	Chevron Aviation Hydraulic Fluid A	Standard Oil of California
MIL-H-5606C	Chevron Aviation Hydraulic Fluid C	Standard Oil of California
MIL-H-5606[b]	MLO 78-294 (used fluid)	c
MIL-C-47220	Coolanol 25R	Monsanto Corp.
MIL-C-47220	Coolanol 35	Monsanto Corp.
MIL-C-47220	Coolanol 45	Monsanto Corp.

[a] Classification uncertain.
[b] Specification uncertain.
[c] Manufacturer uncertain.

TABLE 3. GAS CHROMATOGRAPHY RESULTS: LUBRICATING OILS[a]

r. t.[b] (min)	Brayco 880X Conojet (attenu.)
0.2	2 (sh)
0.3	2
0.8	16
1.3	16
1.4	16
1.7	16 (sh)
1.8	16
2.2	16
3.4	4 (sh)
3.7	4
4.4	8
5.3	16
7.0	64
8.4	64 (sh)
9.2	64
10.0	64
10.5	64 (sh)
11.3	16 (sh)
12.4	16
13.6	16
16.3	4

r. t.[b] (min)	PQ Turbine Oil 8365 (attenu.)	Turbo Oil ETO 2389 (attenu.)
0.4	2	
0.8	4	2 (sh)
1.1	4	2
1.2	4	2
1.3	4	2
1.4	4	2
1.7	8	2
1.8		2
2.0		2
2.4		4
2.7	2	8
3.1	2	8
3.7	8	32
4.5	64	32
5.4	32	
6.1	32 (sh)	64
6.3		64 (sh)
6.6	32 (sh)	
7.2	32	64
9.1	64	64
10.3	16	64
12.3	32	
12.8	32	32
14.3	8	
15.1	8	32
16.4	8	
17.9	8	
18.5	8	
19.5	8	
21.2	2	
22.5		32
23.2	2	
25.1	2	
27.6	2	32
30.1	2	
32.9	2	32
35.7	2	
39.1	2	
42.7	2	
46.5	2	

[a] These fluids were examined under the following conditions--column: stainless steel, 10' x 1/8", 4% OV-101 on Chromosorb G; detector: 1:10 split into F.I.; column temperature: 300°C.

[b] Retention time.

TABLE 4. GAS CHROMATOGRAPHY RESULTS: HYDRAULIC FLUIDS[a]

r. t. (min)	Petrofluid 4606 (attenu.)	Univis J-13 (attenu.)	Peak identification
8.8	2 (sh)	2 (sh)	
9.6	2 (sh)	2 (sh)	
10.3	2 (sh)	2 (sh)	
10.5	2 (sh)	2 (sh)	
11.0	2 (sh)		
11.3	2 (sh)	2 (sh)	
11.5	2	2	
12.0	2	2	
12.4	2	2 (sh)	$C_{10}H_{18}$
13.0	4	4 (sh)	$C_{10}H_{16}$, $C_{11}H_{22}$
13.3	4	4 (sh)	
13.6	4	4	$C_{11}H_{20}$, $C_{11}H_{22}$
14.1	4	4	
14.4	8 (sh)	8 (sh)	
14.7	8 (sh)	8 (sh)	$C_{12}H_{22}$, $C_{13}H_{24}$
14.9	16 (sh)		
15.3	16	16	
15.8	16 (sh)	16 (sh)	$C_{13}H_{28}$
16.2	16 (sh)	16 (sh)	
16.5	32	32	$C_{14}H_{28}$, $C_{14}H_{30}$
17.0	32	32 (sh)	$C_{13}H_{28}$, $C_{14}H_{28}$
17.3	32 (sh)	32	$C_{14}H_{30}$
18.1	32 (sh)	32 (sh)	$C_{14}H_{30}$
18.4	32	32	$C_{15}H_{32}$, $C_{15}H_{30}$, $C_{15}H_{28}$, $C_{15}H_{26}$
18.9	32	32 (sh)	$C_{14}H_{28}$, $C_{14}H_{30}$
19.8	32	32 (sh)	$C_{16}H_{32}$
20.0	32		$C_{16}H_{34}$

[a]These fluids were examined under the following conditions--column: stainless steel, 10' x 1/8", 4% OV-101 on Chromosorb G; detector: 1:10 split into F.I.; column temperature: 50-300°C programed at 8°C/min.

[b]Retention time.

TABLE 4 (Cont'd.). GAS CHROMATOGRAPHY RESULTS: HYDRAULIC FLUIDS[a]

r. t. (min)	Petrofluid 4606 (attenu.)	Univis J-13 (attenu.)	Peak identification
20.4	32	32 (sh)	
20.6	32	32	2,6-di-t-butyl-4-methyl phenol
21.1	32 (sh)	32 (sh)	
21.6	32	32	$C_{17}H_{36}$
22.1	32 (sh)	32 (sh)	
22.4	32 (sh)	32 (sh)	
23.1	32	32	$C_{18}H_{38}$
23.9	32	32	$C_{19}H_{40}$
25.0	8 (sh)		
25.4	8 (sh)	32	$C_{19}H_{38}$
26.3	8	32 (sh)	
26.6	8	32	
27.1	8 (sh)		
27.8	8 (sh)	32	
28.7	8 (sh)		
28.9	8	32 (sh)	
29.6	8 (sh)	32 (sh)	
29.9	8 (sh)		
30.4	8 (sh)		
30.6	8 (sh)		
31.0	8		
31.7	8		
32.5	8 (sh)		
33.0	8 (sh)		
33.5	8 (sh)		
34.3	8 (sh)		
36.2		4	
38.2		2	

TABLE 5. GAS CHROMATOGRAPHY RESULTS: HYDRAULIC FLUID[a]

r. t.[b] (min)	PQ 4226 (attenu.)	Royco 756D (attenu.)	Brayco 756A Micronic (attenu.)	Brayco 7561 Micronic (attenu.)	Brayco 757B Micronic (attenu.)	Peak identification
10.2			2			$C_{10}H_{20}$, $C_{10}H_{22}$
10.8			2			$C_{10}H_{20}$
11.1			2 (sh)			$C_{11}H_{20}$, [illegible], $C_{11}H_{24}$
12.2	2 (sh)		2	2 (sh)	2 (sh)	
13.2	2 (sh)	2 (sh)	2	2 (sh)	2 (sh)	$C_{11}H_{20}$, $C_{11}H_{22}$
13.5			2 (sh)			
13.7	4 (sh)	2 (sh)	2 (sh)	2 (sh)	2 (sh)	
14.0		4 (sh)	4 (sh)	8 (sh)	2 (sh)	
14.3	8 (sh)	4	8 (sh)	8 (sh)	2	$C_{11}H_{20}$, $C_{12}H_{22}$, $C_{12}H_{24}$
14.8			8 (sh)	8 (sh)		$C_{12}H_{22}$, $C_{12}H_{24}$
15.4	16 (sh)	16 (sh)	16 (sh)	16 (sh)	8 (sh)	$C_{12}H_{22}$
16.0	16 (sh)	16 (sh)	16 (sh)	16 (sh)	8 (sh)	$C_{13}H_{24}$, $C_{12}H_{22}$
16.6	16 (sh)	16 (sh)	16 (sh)	16 (sh)	16 (sh)	$C_{13}H_{24}$, $C_{12}H_{26}$, $C_{14}H_{28}$
17.3	32	32	32	32	16	
17.8	32	32	32 (sh)	32	16	
18.4	32 (sh)	32 (sh)	32 (sh)	32 (sh)	16 (sh)	
18.8	32	32	32 (sh)	32 (sh)	16	$C_{14}H_{26}$, $C_{14}H_{28}$
19.3	32	32	32	32	16	$C_{14}H_{26}$, $C_{14}H_{28}$
19.7	32	32 (sh)	32	32	16	$C_{14}H_{26}$, $C_{15}H_{28}$, $C_{15}H_{30}$
20.4	32	32	32	32	16	$C_{15}H_{28}$, $C_{15}H_{30}$, $C_{14}H_{26}$
20.8	32	32	32	32	16	$C_{15}H_{28}$, $C_{15}H_{26}$, $C_{16}H_{30}$, $C_{16}H_{32}$
21.4	32	32	32	32	16	2,6-di-t-butyl-4-methyl phenol?
21.9	32 (sh)	32 (sh)	32 (sh)	32 (sh)	16 (sh)	
22.3	32 (sh)	32 (sh)	32 (sh)	32 (sh)	16 (sh)	$C_{16}H_{30}$, $C_{17}H_{32}$, $C_{17}H_{34}$
22.9	32 (sh)	32 (sh)	32 (sh)	32 (sh)	16 (sh)	
23.7		32 (sh)	32 (sh)	32 (sh)	16 (sh)	$C_{17}H_{32}$, $C_{17}H_{30}$, $C_{18}H_{34}$, $C_{18}H_{36}$
24.4		32 (sh)	32 (sh)	32 (sh)	16 (sh)	
25.6		8				
26.7		8				
26.9	2					
27.0			32 (sh)	32 (sh)	16 (sh)	$C_{19}H_{36}$, $C_{19}H_{38}$
27.5		8 (sh)				
27.9		8 (sh)				
28.3	2					
28.7		8 (sh)				
29.1		8				
29.6	2					
29.8		8 (sh)				
30.3		8 (sh)				
30.9		8 (sh)				
31.2					8	
32.7		8 (sh)				

[a] These fluids were examined under the following conditions--column: stainless steel, 10' x 1/8", 4% [illegible]-101 on Chromosorb [illegible]; detector 1:10 split into F.I.; column temperature: 50-300°C programed at 8°C/min.
[b] Retention time.

TABLE 5 (Cont'd.). GAS CHROMATOGRAPHY RESULTS: HYDRAULIC FLUIDS[a]

r. t.[b] (min)	PQ 4226 (attenu.)	Royco 756D (attenu.)	Brayco 756A Micronic (attenu.)	Brayco 756E Micronic (attenu.)	Brayco 757B Micronic (attenu.)	Peak identification
32.8					8	
33.8		8 (sh)				
33.9					8 (sh)	
34.5					8 (sh)	
34.6		8 (sh)				
35.3	2					
35.8					8	
36.2	2					
36.3					8 (sh)	
36.8	2					
37.5					8 (sh)	

TABLE 6. MASS SPECTRUM OF COOLANOL 25R

```
PRINT MS
GC ID AA       3     SCAN #        5
AQRATE        10     SCTIME        2     RESPWR     1000
HIMASS      1000     THRESH        1

MONSANTO COOLANOL 25R

BACKGR         2     SUBTRT       0      BASE        0
IGNORE        0,     0,      0,    0
MILOUT        10    SEQUEN          11
BASE        18849    *2** 0     % TOTAL IONIZ.         8
```

27	12	93	75	152	25	207	76	277	378	349	10[illegible]
39	19	95	20	153	23	208	12	278	77	350	2[illegible]
41	72	97	43	159	23	212	30	279	44	359	1[illegible]
42	18	103	32	161	28	213	44	280	19	360	2[illegible]
43	330	105	26	163	65	214	28	281	22	361	100[illegible]
53	10	107	53	164	15	215	29	282	18	362	42[illegible]
55	240	109	15	165	52	219	32	283	19	363	15[illegible]
56	63	111	251	175	28	220	43	289	24	364	2[illegible]
57	82	112	28	177	81	221	36	291	37	375	4[illegible]
63	28	113	13	178	14	233	14	303	11	376	1[illegible]
67	16	117	26	179	67	235	143	305	11	377	1[illegible]
69	79	119	19	181	87	236	30	317	12	402	1[illegible]
70	22	121	84	182	12	237	12	318	10	403	22[illegible]
71	17	123	54	189	19	247	30	319	84	404	7[illegible]
77	30	125	28	191	40	249	25	320	26	405	2[illegible]
79	170	133	20	193	461	259	12	330	10	417	3[illegible]
80	11	135	61	194	74	261	25	331	69	430	1[illegible]
81	25	137	85	195	106	262	17	332	20	431	8[illegible]
82	22	138	10	196	12	263	142	333	28	432	16[illegible]
83	651	139	12	201	17	264	48	345	13	433	34[illegible]
84	415	145	34	203	15	265	61	346	31	434	13[illegible]
85	656	147	26	205	124	266	17	347	379	435	4[illegible]
86	69	149	34	206	18	275	28	348	138	441	1[illegible]
91	17	151	237								

TABLE 7. MASS SPECTRUM OF COOLANOL 45

PRINT MS
GC ID AA 4 SCAN #
AQRATE 10 SCTIME 2 RESPWR 1000
HIMASS 1000 THRESH 1

MONSANTO COOLANOL 45

BACKGR 2 SUBTRT 0 BASE 0
IGNORE 0, 0, 0, 0
MILOUT 10 SEQUEN 15
BASE 6930 *2** 0 % TOTAL IONIZ. 6

27	21	99	12	177	25	261	18	346	36	443	20
29	27	103	34	179	49	263	117	347	46	444	23
39	23	105	21	185	68	264	20	348	16	445	937
41	117	107	34	189	12	265	11	349	16	446	361
42	17	109	34	191	29	273	22	359	10	447	120
43	158	110	42	193	22	274	10	361	30	448	23
53	10	111	849	203	13	275	23	373	20	459	27
54	11	112	631	205	19	277	30	375	58	460	14
55	245	113	1000	207	87	289	21	376	23	473	14
56	74	114	133	208	13	291	47	385	34	486	25
57	618	117	11	209	226	292	10	387	20	487	104
58	32	119	18	210	30	302	14	388	15	488	[illegible]9
63	25	121	46	211	13	303	21	389	16	489	21
67	35	123	52	217	10	315	26	390	11	499	10
68	27	125	34	219	24	317	27	401	20	504	10
69	701	131	12	220	11	318	27	403	38	514	12
70	199	133	10	221	282	319	209	404	16	515	119
71	532	135	37	222	46	320	66	405	10	516	55
72	25	137	57	223	71	321	115	414	47	517	15
77	19	138	11	224	15	322	24	415	55	529	23
79	85	145	17	233	20	331	24	416	25	530	13
81	51	147	21	235	50	333	271	417	32	542	35
82	23	149	33	236	14	334	83	427	23	543	159
83	120	151	113	237	20	335	43	429	13	544	289
84	67	157	10	239	10	336	11	430	83	545	494
85	30	161	17	247	21	341	11	431	665	546	248
91	16	163	34	248	17	342	12	432	273	547	76
93	76	165	54	249	36	343	17	433	215	548	13
95	32	173	16	250	33	344	22	434	64	623	12
97	38	175	16	251	10	345	31	435	16	735	11
98	31										

TABLE 8. SUMMARY OF LUBRICATING-OIL DYNAMIC TESTS

Test No.	Sample: Type	Sample: MW	Sample: Wt. used (g)	Conditions: Duration (hr)	Conditions: Temp. (°C)	Conditions: Flow (ml/min)	Volatiles[a]: Wt. (mg)	Mist[b]: Wt. (mg)	Mist[b]: MW	Residue: MW
1	Turbo Oil ETO 2389	421	11.53	1.5	190	~ 400	113.3 [?]	110	-	401
2	Turbo Oil ETO 2389	421	10.81	0.5	250	~ 500	68.2 [4.6]	690	372	415
3	Brayco Conojet 880X	403	10.79	1	200	~ 500	44.6 [3.1]	60	-	406
4	None[c]	-	-	1.5	RT	~ 450	28	-	-	-
5	Brayco Conojet 880X	403	10.92	0.5	300	~ 450	60.9 [21.6]	2190	388	402
6	MLO 78-295	-	10.38	1.5	200	~ 500	30.1 [7.1]	110	-	-

[a] Materials volatile at room temperature. The top values given are the total volatiles collected (mainly water); the values in the brackets are the actual degradation products.
[b] Materials which volatilized during the test, but were involatile at room temperature.
[c] Test was performed at room temperature in the absence of oil sample to determine the "blank" of the system.

TABLE 9. VOLATILE PRODUCTS OBTAINED ON THERMAL TREATMENT OF SELECTED LUBRICATING OILS UNDER DYNAMIC CONDITIONS

	Turbo Oil ETO 2389	Brayco Conojet 880X		MLO 78-295
	250°C (mg/g)	200°C (mg/g)	300°C (mg/g)	200°C (mg/g)
CO_2	0.147	0.067	0.296	0.145
C_2-species	0.004	-	0.006	Trace[a]
C_3-species	0.006	-	0.062	Trace
C_4-species	0.009	0.008	0.105	Trace
C_5-species	0.007	0.021	0.008	Trace
C_6-species	0.007	0.014	0.012	Trace
C_7-species	0.007	0.076	0.093	0.004
C_8-species	0.022	0.023	1.181	0.032
C_9-C_{12}-species	0.013	-	0.032	0.045
Benzene	-	-	-	0.001
Toluene	0.009	0.007	-	0.006
C_2-benzenes	0.025	-	-	0.022
C_3-benzenes	0.010	-	-	0.003
C_6-benzenes	-	-	-	0.039
Acetaldehyde	0.007	-	-	0.001
Propionaldehyde	0.011	-	-	-
n-Butanal	0.025	-	-	Trace
Crotonaldehyde	-	-	0.001	-
Tiglaldehyde	0.004	-	0.001	-
n-Pentanal	0.031	-	-	0.001
n-Hexanal	-	-	-	0.001
2-Methyl-2-pentenal	-	-	0.012	-
n-Heptanal	0.022	-	-	-
2-Ethylhexanal	-	-	-	0.021
Acetone	0.001	0.015	0.018	0.011
Methyl vinyl ketone	-	-	Trace	-
Methyl ethyl ketone	-	-	Trace	0.002
2-Pentanone	-	-	-	0.002
2-Hexanone	0.043	-	-	-
Cyclopentanone	-	-	-	Trace
2-Propanol	-	-	-	Trace
C_4-alcohols	0.001	0.001	0.001	Trace
C_8-alcohols	-	-	0.001	0.291
C_9-alcohols	-	-	0.001	0.021
4-Methyl-2-ethyl-1,3-dioxolane	-	-	0.001	-
Dimethylformamide	-	0.017	-	-

[a] <0.0005 mg/g.

TABLE 10. MASS SPECTRUM OF TURBO OIL ETO 2389

```
PRINT MS
GC ID AA       6    SCAN #      6
AQRATE         6    SCTIME      2     RESPWR    500
HIMASS       500    THRESH      2

EXXON TURBO OIL ETO 2389

BACKGR     2    SUBTRT    0    BASE     0
IGNORE    0,     0,     0,     0
MILOUT   10   SEQUEN         18
BASE    21331   *2** 0    % TOTAL IONIZ.     5
```

26	18	66	14	97	141	128	582	168	19	214	51
27	150	67	133	98	326	129	277	169	31	215	17
29	331	68	209	99	419	130	34	170	109	216	61
30	17	69	601	100	50	131	41	171	47	217	133
31	23	70	210	101	48	137	12	172	17	218	156
38	18	71	494	102	14	138	10	173	59	219	340
39	146	72	40	103	54	139	27	182	56	220	65
41	646	73	80	104	19	140	78	183	34	223	17
42	220	74	25	105	25	141	810	184	52	226	54
43	767	75	20	107	13	142	116	185	85	227	170
44	32	76	16	108	24	143	30	186	16	228	29
45	77	77	36	109	146	144	18	187	19	229	30
50	15	79	33	110	75	145	167	188	146	230	40
51	32	80	37	111	55	146	45	189	37	231	83
52	16	81	149	112	163	147	89	190	12	232	11
53	53	82	88	113	287	148	12	197	19	240	16
54	50	83	194	114	38	149	198	198	39	241	32
55	604	84	296	115	105	150	26	199	85	242	19
56	519	85	683	116	29	152	16	200	44	243	30
57	1000	86	160	117	35	153	24	201	35	244	31
58	92	87	92	119	23	154	36	202	14	245	59
59	34	88	13	121	21	155	214	203	33	257	11
60	74	89	44	122	17	156	64	204	16	271	19
61	44	91	31	123	42	157	24	205	20	272	52
62	10	93	30	124	16	158	24	210	12	284	11
63	27	94	21	125	40	159	126	211	11	285	32
64	19	95	63	126	117	160	16	212	101	286	39
65	32	96	38	127	979	165	10	213	263	313	10

TABLE 11. MASS SPECTRUM OF MIST COLLECTED ON HEAT TREATMENT OF TURBO OIL ETO 2389 AT 250°C

```
PRINT MS
GC ID AA       9    SCAN #       9    DATE
A
 GRATE        10    SCTIME       2    RESPWF   1000
HIMASS      1000    THRESH       1

MIST COND FROM TEST#2 EXXON TURBO OIL

BACKGR     2    SUBTRT    0    BASE        0
IGNORE    0,     0,     0,     0
MILOUT   10   SEQUEN         38
BASE    21584 *2** 0    % TOTAL IONIZ.        4
```

15	21	70	325	109	195	151	10	203	92	259	28
18	14	71	466	110	104	152	26	204	45	260	28
26	54	72	72	111	74	153	31	205	41	261	15
27	276	73	124	112	186	154	46	210	33	269	20
29	485	74	37	113	367	155	277	211	23	270	13
30	37	75	29	114	53	156	92	213	229	271	19
31	72	76	29	115	133	157	39	214	538	272	76
36	22	77	53	116	44	158	38	215	173	273	201
37	11	78	13	117	43	159	172	216	140	274	44
38	30	79	36	119	17	160	23	217	337	275	10
39	255	80	44	121	28	165	14	218	360	279	18
40	33	81	147	122	19	166	12	219	587	280	13
41	707	82	116	123	47	168	36	220	162	281	11
42	368	83	277	124	21	169	49	221	22	283	14
43	892	84	425	125	57	170	210	223	49	284	14
44	75	85	659	126	175	171	84	224	13	285	41
45	141	86	238	127	1000	172	30	226	11	286	163
50	33	87	136	128	642	173	88	227	157	287	124
51	63	88	21	129	375	181	11	228	346	288	31
52	21	89	51	130	52	182	107	229	64	300	69
53	82	91	23	131	46	183	61	230	81	302	14
54	96	93	38	135	10	184	104	231	113	312	20
55	732	94	25	137	13	185	191	232	212	313	50
56	553	95	74	138	15	186	35	233	31	314	23
57	897	96	60	139	36	187	43	241	48	328	10
58	144	97	191	140	140	188	284	242	85	329	18
59	55	98	391	141	766	189	67	243	70	341	15
60	112	99	489	142	193	190	25	244	86	343	10
61	74	100	85	143	42	191	21	245	101	344	21
63	32	101	58	144	26	196	17	246	169	356	15
64	22	102	20	145	239	197	32	247	20	357	37
65	44	103	72	146	59	198	70	253	17	371	20
66	17	104	36	147	129	200	287	255	52	384	13
67	170	105	38	148	15	201	91	257	15	386	31
68	268	107	15	149	285	202	37	258	39	387	10
69	620	108	33	150	55						

TABLE 12. MASS SPECTRUM OF TURBO OIL ETO 2389 AFTER HEAT TREATMENT AT 250°C

```
PRINT MS
GC ID AA      5    SCAN #      4
ACRATE       10    SCTIME      2    RESPWR  1000
HIMASS     1000    THRESH      1

RESIDUE TEST#2 EXXON TURBO OIL

BACKGR    2    SUBTRT    0    BASE      0
IGNORE   0,    0,    0,    0
MILOUT   10   SEQUEN        20
BASE     7008 *2** 0   % TOTAL IONIZ.     6
```

26	11	83	102	125	28	173	41	219	370	273	23
27	46	84	187	126	96	179	11	220	65	279	11
29	81	85	707	127	1000	182	78	223	15	282	15
39	58	86	97	128	511	183	53	225	21	283	13
41	293	87	39	129	290	184	93	226	124	284	42
42	88	89	19	130	25	185	109	227	533	285	154
43	338	93	14	131	19	186	14	228	110	286	117
45	22	94	16	138	13	187	21	229	61	287	30
53	24	95	55	139	23	188	166	230	61	299	31
54	21	96	36	140	65	189	28	231	181	300	25
55	290	97	93	141	959	190	12	232	32	302	13
56	245	98	226	142	139	191	10	240	49	312	45
57	899	99	203	143	24	196	17	241	132	313	133
58	38	100	21	145	105	197	39	242	69	314	27
59	14	101	23	146	26	198	74	243	86	341	27
60	35	103	32	147	77	199	123	244	38	344	16
61	11	105	11	149	111	200	80	245	187	357	34
65	10	107	20	150	11	201	56	246	22	358	11
67	88	108	71	152	15	202	22	254	14	367	15
68	139	109	67	153	14	203	23	255	34	368	30
69	377	110	19	154	47	204	12	257	29	369	16
70	90	111	27	155	303	205	15	258	12	370	14
71	264	112	94	156	78	210	43	259	47	371	36
72	14	113	301	157	18	211	22	260	17	372	17
73	31	114	28	158	21	212	114	261	12	384	11
74	11	115	40	159	110	213	595	268	16	385	52
77	10	116	15	160	10	214	128	269	13	386	16
79	19	117	22	168	20	215	41	270	26	387	10
80	17	121	13	169	27	216	102	271	40	399	10
81	120	123	31	170	160	217	202	272	115	415	17
82	38	124	15	171	58	218	174				

TABLE 13. MASS SPECTRUM OF BRAYCO CONOJET 880X OIL

```
PRINT MS
GC ID AA      3    SCAN #    6
AGRATE        6    SCTIME    2     RESPWR     500
HIMASS      500    THRESH    2

BAYCO CONOJET 880X

BACKGR      2     SUBTRT     0    BASE       0
IGNORE    0,     0,     0,     0
MILOUT   10    SEQUEN         8
BASE     23763   *2** 0    % TOTAL IONIZ.       8
```

18	30	69	320	101	128	133	23	169	37	228	10
27	88	70	252	102	58	135	10	170	21	229	20
29	179	71	434	104	14	137	12	171	304	230	15
30	11	72	62	106	21	138	13	172	34	231	10
31	38	73	71	107	17	139	52	173	17	241	35
36	20	74	17	109	27	140	56	177	12	242	14
38	10	77	27	110	23	141	503	179	16	243	31
39	61	78	11	111	85	142	49	183	13	245	20
40	10	79	26	112	234	143	41	184	14	255	23
41	312	81	94	113	225	144	17	185	139	256	12
42	169	82	66	114	40	145	20	186	19	259	11
43	454	83	236	115	89	147	15	189	20	262	15
44	53	84	200	116	37	152	59	195	10	263	44
45	47	85	92	117	31	153	23	197	21	269	36
51	11	86	16	118	11	154	20	198	109	270	13
53	21	87	35	119	19	155	61	199	1000	275	15
54	41	88	13	121	20	156	15	200	218	283	126
55	415	89	24	122	10	157	52	201	25	284	30
56	175	91	36	123	41	158	15	203	22	287	17
57	591	93	14	124	14	159	178	206	17	301	50
58	111	94	12	125	49	160	15	212	27	302	13
59	191	95	45	126	28	161	16	213	37	316	10
60	37	96	43	127	80	163	16	214	10	367	11
61	38	97	131	128	30	164	13	218	15	368	33
65	16	98	121	129	112	165	12	219	156	369	11
67	76	99	69	130	18	166	14	220	39	382	11
68	52	100	130	131	15	167	51	227	28		

TABLE 14. MASS SPECTRUM OF MIST COLLECTED ON HEAT TREATMENT OF BRAYCO CONOJET 880X OIL AT 300°C

```
PRINT MS
GC ID AA       6    SCAN #     6
AQRATE         6    SCTIME     2     RESPWR    500
HIMASS       500    THRESH     2

MIST FROM COLUMN TEST #5 BRAYCO CONOJET

BACKGR     2    SUBTRT    0    BASE      0
IGNORE    0,    0,    0,    0
MILOUT    10   SEQUEN          26
BASE     25242  *2** 0   % TOTAL IONIZ.       7
```

15	15	61	31	91	24	119	20	154	33	197	29
18	23	63	15	93	18	121	14	155	64	198	130
26	18	65	23	94	10	122	10	156	25	199	1000
27	121	67	105	95	48	123	48	157	43	200	236
29	253	68	63	96	40	124	18	158	24	201	42
30	13	69	312	97	149	125	47	159	183	212	32
31	72	70	236	98	131	126	30	160	20	213	36
38	13	71	560	99	92	127	97	165	13	219	25
39	107	72	59	100	131	128	27	166	47	227	28
40	17	73	73	101	127	129	109	167	103	229	24
41	531	74	29	102	16	130	13	168	13	230	15
42	218	75	12	103	78	133	22	169	46	231	11
43	689	77	35	104	13	135	11	170	19	241	39
44	53	78	10	107	17	137	15	171	220	243	23
45	95	79	29	108	14	138	20	172	37	245	20
50	12	80	14	109	26	139	59	173	19	255	23
51	14	81	121	110	23	140	78	176	13	256	10
53	39	82	57	111	92	141	470	177	12	259	14
54	38	83	196	112	218	142	71	183	11	269	27
55	541	84	209	113	233	143	43	184	12	275	10
56	265	85	127	114	48	144	11	185	129	283	65
57	778	86	25	115	120	145	17	186	25	284	13
58	146	87	67	116	58	152	37	189	11	301	21
59	242	88	10	117	44	153	22	196	11	368	10
60	67	89	27								

TABLE 15. MASS SPECTRUM OF BRAYCO CONOJET 880X OIL AFTER HEAT TREATMENT AT 300°C

```
PRINT MS
GC ID AA       7    SCAN #      6
AQRATE         6    SCTIME      2       RESPWR      500
HIMASS       500    THRESH      2

RESIDUE TEST #5 BRAYCO CONOJET

BACKGR       2      SUBTRT     0    BASE       0
IGNORE      0,     0,     0,     0
MILOUT      10    SEQUEN        27
BASE      17951   *2** 0     % TOTAL IONIZ.        6
```

15	16	60	79	88	16	116	55	147	10	189	12
26	24	61	36	89	29	117	45	152	37	197	19
27	153	63	12	91	21	118	10	153	18	198	85
29	305	65	22	93	21	119	22	154	28	199	976
30	16	67	125	94	19	121	19	155	55	200	182
31	79	68	76	95	59	123	75	156	29	201	26
38	12	69	434	96	64	124	20	157	45	212	20
39	152	70	304	97	161	125	53	158	35	213	43
40	33	71	687	98	174	126	31	159	191	219	20
41	853	72	81	99	84	127	93	160	25	225	14
42	266	73	95	100	196	128	25	165	11	227	29
43	1000	74	32	101	133	129	107	166	27	229	19
44	67	77	25	102	26	130	16	167	71	230	11
45	105	78	11	103	99	133	18	168	12	241	33
50	12	79	27	107	20	135	11	169	46	243	21
51	16	80	21	108	15	137	15	170	17	245	19
53	41	81	164	109	24	138	41	171	221	255	22
54	58	82	80	110	30	139	68	172	31	256	12
55	709	83	281	111	88	140	64	173	17	259	10
56	313	84	282	112	301	141	579	183	10	269	18
57	967	85	302	113	250	142	83	184	12	283	44
58	177	86	38	114	63	143	53	185	126	301	17
59	302	87	67	115	156	145	21	186	21		

TABLE 16. SUMMARY OF THERMAL OXIDATIVE TESTS PERFORMED UNDER QUIESCENT CONDITIONS

Sample		Conditions			Volatiles	
Type	Wt (g)	Dur. (hr)	Temp. (°C)	P[a] (mm)	Wt (mg)	Compounds
Turbo Oil ETO 2389	5.14	2.0	200-205	602	3.5	H_2O, CH_3CHO, CH_3CH_2CHO, $CH_3(CH_2)_3CHO$
Brayco Micronic 756E	5.04	1.5	130-138	603	4.3	H_2O, $CH_2{=}C(CH_3)CO_2CH_3$, $CH_3CH_2CH{=}CH_2$, $(CH_3)_2CO$, $(CH_3)_3CHOH$
Coolanol 25R	5.03	2.0	172-178	603	4.4	H_2O, $CH_3CH_2COCH_2CH_3$, $C_2H_5CH(C_2H_5)$-CH_2OH, $C_2H_5CH(C_2H_5)CHO$
MLO78-294	5.12	1.5	131-139	603	7.4	For listing of products formed, see Table 17
Coolanol 45	4.01	2.0	172-182	600	7.7	For listing of products formed, see Table 17

[a]Initial pressure of air prior to sample heating.

TABLE 17. VOLATILE PRODUCTS FORMED ON THERMAL OXIDATIVE DEGRADATION OF SELECTED FLUIDS UNDER QUIESCENT CONDITIONS

Products	MLO 78-294 131-139°C (mg/g)	Coolanol 45 172-182°C (mg/g)
H_2O	0.103	0.375
CO_2	Trace	0.046
C_5 - species	0.002	-
C_6 - species	0.037	-
C_7 - species	0.080	-
C_8 - species	0.036	-
C_9 - C_{10} - species	<0.1	-
C_{11} - C_{13}	~ 0.7	-
Benzene	0.010	0.059
Toluene	0.004	0.120
C_2 - benzenes	0.011	-
Acetone	0.009	-
n-Butanal	-	0.006
n-Pentanal	-	0.015
Tetrahydrofuran	0.001	-
_t_-Butyl alcohol	Trace	-
Methyl methacrylate	0.080	-
Di-t-butyl peroxide	<0.1	-
2-Ethylhexanol	-	1.58

Trace <0.0005 mg/g

TABLE 18. SUMMARY OF LINE-RUPTURE SIMULATION TESTS

Sample		Conditions			Mist		Volatiles[a]	
Type	Wt (g)	Dur. (hr)	Temp (°C)	Flow (ml/min)	Wt (g)	(%)[b]	Wt (mg)	(%)[b]
Turbo Oil ETC 2389	2.4	0.75	450	250	1.32	55	293.8	12.2
Brayco Conojet 880X	1.7	0.4	450	250	0.97	57	270.8	15.8
PQ Turbine Oil 8365	2.4	0.4	450	250	1.40	58	276.6	11.6
MLO 78-295	2.3	0.5	450	250	1.54	67	257.8	11.2
Brayco 756E	2.1	0.5	450	250	1.27	60	193.6	9.2
MLO 78-294	2.2	0.5	450	250	1.82	83	204.0	9.3
Coolanol 25R	~2	0.5	450	250	1.80	90	178.8	8.9
Coolanol 45	1.9	0.4	450	250	1.03	54	281.7	14.7

[a]Products are listed in Table 19.
[b]Percent of fluid employed.

TABLE 19. VOLATILE PRODUCTS FORMED BY AIRCRAFT FLUIDS ON EXPOSURE TO STEEL SURFACE AT 450°C

	Lubricating oils				Hydraulic fluids		Heat-transfer fluids	
	Turbo Oil 2389 (mg/g)	Brayco 880X (mg/g)	PQ 8365 (mg/g)	MLO 78-295 (mg/g)	Brayco 756E (mg/g)	MLO 78-294 (mg/g)	Coolanol 25R (mg/g)	Coolanol 45 (mg/g)
CO	8.6	8.5	6.4	6.0	4.4	1.7	n.d.[a]	9.4
H_2O	49.3	67.6	46.8	39.8	40.4	44.6	28.8	55.2
CO_2	26.8	25.5	14.1	23.4	12.8	7.16	12.0	19.0
CH_4	0.10	0.09	0.20	0.05	0.02	-	n.d.	0.18
C_2-species	6.15	6.82	10.2	1.99	1.14	1.90	2.83	6.68
C_3-species	3.58	6.62	4.73	2.20	1.28	0.492	0.192	2.94
C_4-species	2.00	3.91	6.95	1.87	0.978	1.59	0.844	3.52
C_5-species	1.06	5.32	1.90	2.02	0.740	1.17	8.88	0.467
C_6-species	5.53	3.35	2.63	3.55	0.789	0.870	0.843	0.467
C_7-species	0.155	3.99	2.94	3.61	1.03	0.576	0.049	10.1
C_8-species	3.13	8.37	10.8	13.8	1.43	0.943	0.039	4.21
C_9-species	0.195	1.17	0.230	1.83	0.981	0.268	-	-
C_{10}-C_{14}-species	-	-	-	1.18	-	12.2	-	-
Benzene	-	-	-	-	-	-	0.002	-
Toluene	Trace[b]	0.108	0.022	-	0.134	0.146	-	0.130
C_2-benzenes	-	-	-	-	0.310	0.193	-	-
Formaldehyde	0.388	1.27	0.482	0.619	0.169	1.45	0.008	0.629
Acetaldehyde	1.59	3.97	1.62	2.22	1.21	2.01	1.43	2.70
Acrolein	0.918	1.48	0.455	0.796	0.169	0.489	0.258	0.700
Propionaldehyde	2.11	2.27	2.02	3.01	0.058	0.495	2.69	3.74
2-Methylpropenal	-	0.402	0.123	0.569	0.304	0.433	-	0.067
n-Butanal	2.33	1.38	1.17	1.31	0.214	0.404	1.12	2.22
Crotonaldehyde	0.332	0.084	0.024	-	0.030	0.005	0.006	0.548
n-Pentanal	2.08	1.60	0.714	-	0.242	-	-	1.38
n-Hexanal	0.381	-	0.008	-	0.756	-	-	0.780
2-Ethylbutanal	-	-	-	-	-	-	8.15	-
2-Methyl-2-pentenal	-	-	-	-	-	-	0.156	-
n-Heptanal	0.360	-	-	-	-	-	-	-
2-Ethylhexanal	-	-	0.730	-	-	-	-	8.83
C_8-aldehyde	-	-	-	-	-	0.151	-	-
Acetone	1.57	3.13	0.375	2.15	2.04	2.39	-	-
Methyl vinyl ketone	0.063	0.905	0.398	0.715	0.283	0.381	-	-
Methyl ethyl ketone	2.29	1.51	2.00	1.29	1.19	0.837	0.005	2.55
2-Pentanone	0.109	-	-	0.590	0.398	-	-	-
3-Pentanone	-	-	-	-	-	-	4.75	0.076
Methyl isobutyl ketone	-	-	0.582	-	-	-	-	-
Cyclopentanone	-	-	-	0.004	0.012	0.003	-	-
3-Heptanone	-	-	-	-	-	-	0.012	4.71
4-Heptanone	-	-	-	-	-	-	-	0.398
5-Hexen-2-one	-	0.004	-	-	-	-	-	-
C_9-ketone	-	-	-	-	-	-	0.044	-
Methanol	1.19	3.76	2.70	0.632	0.942	1.45	0.328	2.05
Ethanol	0.026	0.044	0.096	0.008	Trace	0.014	0.018	0.083
n-Propanol	0.001	-	-	-	-	-	-	-
Allyl alcohol	0.004	0.050	0.009	0.004	0.004	-	-	-
n-Butanol	-	-	-	-	-	-	-	0.149
2-Buten-1-ol	-	-	0.027	-	-	-	-	0.036
3-Pentanol	-	-	-	-	-	-	0.084	-
2-Ethyl-1-butanol	-	-	-	-	-	-	10.0	-
C_6-alcohols	-	-	-	-	-	-	-	1.13
2-Ethylhexanol	-	-	-	-	-	-	-	3.22
Methyl formate	Trace	0.044	0.023	0.008	-	0.016	0.033	1.49
Ethyl formate	-	-	-	-	-	-	-	0.135
n-Propyl formate	-	-	-	-	-	-	-	0.008
2-Ethyl-1-butyl formate	-	-	-	-	-	-	2.00	-
Methyl acetate	0.021	0.026	0.012	0.012	-	0.024	-	-
Methyl acrylate	-	-	-	-	0.032	-	-	-
Methyl methacrylate	-	-	-	0.030	15.3	10.5	-	-
sec-Butyl methacrylate	-	-	-	-	0.190	-	-	-
Methyl propionate	-	0.006	0.004	Trace	0.028	-	-	-
Vinyl propionate	-	-	-	-	-	-	0.059	-
Dimethoxyethane	-	0.175	-	-	-	-	0.029	-
1-Methoxy-1-hexoxyethane	-	-	-	-	-	-	0.024	-
1,1-Dihexoxyethane	-	-	-	-	-	-	0.228	-
1,1-Dihexoxypropane	-	-	-	-	-	-	0.165	-
Furan	-	0.419	-	-	-	-	-	-
2-Methyltetrahydrofuran	0.070	0.811	0.406	-	0.034	-	0.006	0.120
Cis-2,5-dimethyltetrahydrofuran	6.51	-	0.008	-	-	-	-	-
2-Butyltetrahydrofuran	-	0.185	-	-	-	-	-	-
2,3-Dihydrofuran	0.016	-	-	-	-	-	-	-
2,3-Epoxybutane	-	-	-	0.037	-	-	-	-
Formic acid	-	-	-	-	-	-	-	0.099
Acetic acid	Trace	0.044	-	0.004	0.004	-	0.018	0.125
Propionic acid	-	-	-	-	-	-	0.006	-
2-Ethylbutanoic acid	-	-	-	-	-	-	0.017	-

[a] Not determined.
[b] < 0.0005 mg/g.